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Control of Reentrained Dust from Paved Streets

PEDCo-Environmental, Inc, Kansas City, Mo

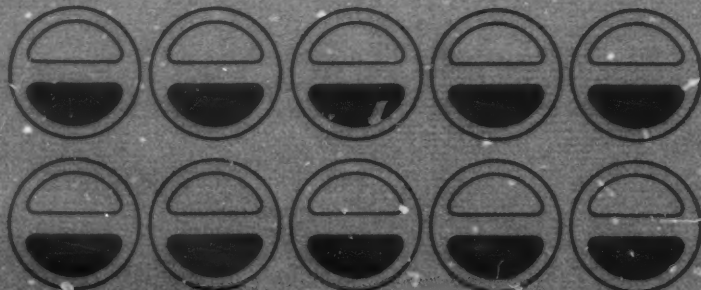
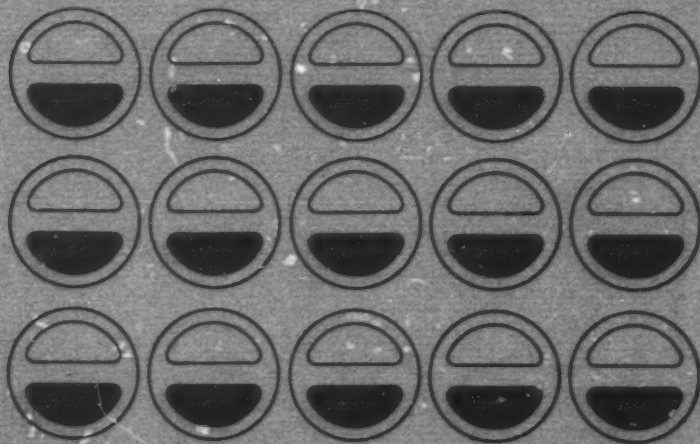
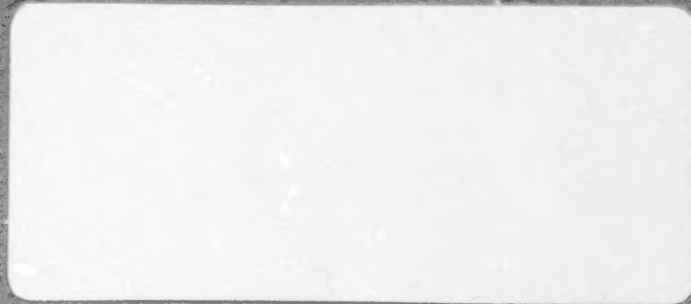
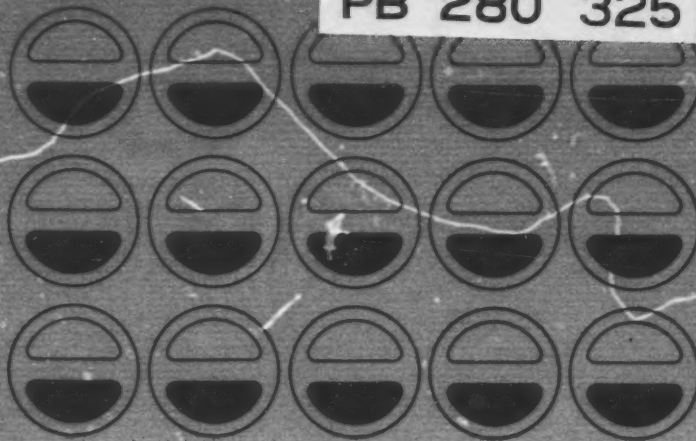
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16. ABSTRACT The report is a comprehensive review of the problem of reentrained dust from paved streets. Information was obtained from literature review, collection of unpublished data from traffic-related air and water pollution studies, survey of comments from public works officials, and five different field studies to evaluate the effectiveness of specific reentrained dust control measures. All of the assembled data show agreement that the effect of traffic-related particulate emissions in the form of reentrained dust is one of the most important sources of particulate matter in metropolitan areas. The results of the field studies conducted in the project and analysis of six other studies were inconclusive with regard to the effectiveness of improved street cleaning as a means of improving air quality. None of the street cleaning methods proved to be effective in all studies in which they were evaluated. In addition, the data generated in the field studies did not show a consistent relationship between street surface loadings and nearby particulate concentrations. The report gives information on the costs for conventional street cleaning operations and possible modifications to improve air quality. Examples of existing state and local regulations and ordinances for controlling reentrained dust are presented.		
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PEDCo ENVIRONMENTAL

11499 CHESTER ROAD
CINCINNATI, OHIO 45246
(513) 782-4700

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Prepared by
PEDCo-ENVIRONMENTAL, INC.
2480 Pershing Road
Kansas City, Missouri 64108

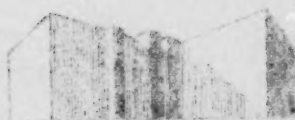
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U.S. ENVIRONMENTAL PROTECTION AGENCY

1200 MONTGOMERY AVENUE
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(202) 368-5000

U.S. ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C. 20460

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Street cleaning was done on special schedules in Kansas City and Cincinnati by the respective city street departments. Coordination of street cleaning activities with PEDCo's field studies was handled by Mr. Don Ewbank of the Kansas City Streets Division and Mr. Michael Donnelly of the Cincinnati Highway Maintenance Division.

The EPA Project Officer was Mr. Dewayne Durst, Chief, Air Support Branch, Region VII. Messrs. Dallas Safriet, Edward Lillis, and Thompson Pace of the Monitoring and Data Analysis Division and Mr. David Dunbar of the Control Programs Development Division also provided on-going project guidance and advice. The principal authors of the report were Mr. Kenneth Axetell and Ms. Joan Zell.

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EXECUTIVE SUMMARY

SCOPE AND PURPOSE

This report is the first comprehensive review on the topic of reentrained dust from paved streets. Its primary purpose is to evaluate control measures for reducing emissions of reentrained dust. Information for the review and evaluation was obtained by several different methods: a literature review, collection of unpublished data from traffic-related air pollution studies, compilation of cost data, survey of public works officials, and design and implementation of five different field studies to evaluate the effectiveness of specific reentrained dust control measures.

REENTRAINED DUST

The term "reentrained dust" refers to small particles that are thrown from the street surface by contact with vehicle tires or are induced to become airborne by the vortexes from passing vehicles. In addition, motor vehicles emit particulate matter directly in engine exhaust gases, from wear of various parts such as bearings and brake linings, and from abrasion of tires against the road surface. It appears from studies of total traffic-related impact that the reentrained portion is an order of magnitude greater than the direct emissions accounted for by currently available emission factors for vehicle exhaust (0.34 g/veh-mi) and tire wear (0.20 g/veh-mi).

All of the assembled data show agreement on the effect of traffic-related particulate emissions and, in particular, reentrained dust--this is one of the most important particulate

source categories in every metropolitan area. In most urban areas where particulate analyses have been performed recently, some reduction in reentrained dust emissions has been shown to be necessary in order to attain the primary ambient air quality standards.

Particulate emissions from a street were demonstrated to be directly proportional to the traffic volume along that street within the ranges of traffic volumes tested. This assumption has previously been made in basing emission factors for reentrained dust on vehicle-miles of travel.

Suspended particulate samples taken near streets in the present field studies had relatively large particle sizes--a mass median diameter of 15 u and approximately 22 percent by weight greater than 30 u. Calculated fallout rates averaged 14 percent at 10 m, 26 percent at 20 m, and 34 percent at 30 m from the street.

Mineral matter was identified microscopically (polarized light microscope) to constitute an average of 59 percent by weight of the material in the samples. Combustion products were a surprisingly large 40 percent of the weight. Biological matter and tire tread together comprised a little more than one percent of the particulate collected near streets. Inorganic lead was determined chemically to account for an average of one to two percent of the suspended particulate.

MATERIAL ON STREET SURFACES

Published information was compiled to identify the important processes by which materials are deposited on street surfaces and the processes, including reentrainment, by which they are removed. Typical annualized deposition and removal rates for each of the processes were estimated for a four-lane street with a traffic volume of 10,000 vehicles per day. These deposition and removal rates, which

should not be considered descriptive of any single day on a particular street, are summarized below:

<u>Deposition process</u>	<u>Typical rate, lb/curb-mi/day</u>	<u>Removal process</u>	<u>Typical rate, lb/curb-mi/day</u>
Mud and dirt carryout	100	Reentrainment	100
Litter	40	Displacement	40
Biological debris	20	Wind erosion	20
Ice control compounds	20	Rainfall runoff	50
Dustfall	10	Sweeping	35
Pavement wear & decomposition	10		
Vehicle-related (incl. tire wear)	17		
Spills	<2		
Erosion from adjacent areas	20		

Deposition and removal rates are not equal in the above tabulation because of approximations used for individual processes. Based on this crude mass balance for materials entering and leaving a typical street, it appears that almost half the material may leave the street as particulate air pollution by either reentrainment or wind erosion.

POTENTIAL CONTROL MEASURES

Several control measures were identified which could possibly reduce the amount of suspended particulate caused by reentrainment from paved streets. All but one of these potential measures was concerned with reducing the amount of material on street surfaces, under the initial assumption that reducing street surface loadings would proportionately reduce the amount of material that is available for reentrainment. The measures which were proposed and then evaluated in subsequent project work are:

- Improved street cleaning
 - Broom sweeping
 - Vacuum sweeping
 - Regenerative air sweeping
 - Flushing
- Modified snow and ice control procedures
 - Replace sand with salt or a salt/sand mixture
 - Plow instead of sand or salt
 - Remove anti-skid material as soon as possible
 - Apply less material
- Control of dirt and mud carryout from major sources (e.g., construction sites, truck terminals)
- Control of dirt and mud carryout from ubiquitous sources (e.g., unpaved parking areas, shoulders, and driveways)
- Reduction in traffic volumes on a street

FIELD STUDIES

Five field studies were done in conjunction with this project--three were comparisons of the air quality impacts of alternative street cleaning techniques, one was a comparison of the air quality impacts of different methods of controlling mud carryout at a construction site, and the remaining one was intended to investigate the relationships among traffic volumes, street surface loadings, and particulate concentrations near the street.

In addition, particulate air quality data were obtained for six cities in which potential control measures had been implemented--some type of street cleaning program in five cities and control of trackout sources in the sixth. The air quality data were reviewed to determine whether the programs had a discernible effect on particulate concentrations.

The findings of the project field studies and the six other data analyses were inconclusive with regard to the effectiveness of improved street cleaning as a control

measure. Although some of the street cleaning methods on occasion appeared to reduce particulate concentrations near the streets that were cleaned, none of the methods proved to be effective in all of the studies in which they were evaluated, as shown below:

<u>Cleaning method</u>	<u>Studies in which method was effective</u>	<u>Studies in which method was ineffective</u>
Broom sweeping	1	2
Vacuum sweeping	0	2
Regenerative air sweeping	0	1
Flushing	2	2
Sweeping and flushing	0	1

In addition, it was concluded from data generated in the field studies that there is no consistent relationship between street surface loadings and nearby particulate concentrations. Correlation between these two variables was not improved when either the street loading in traffic lanes or the loading of material less than 44 μ diameter was substituted for total street loading. Since the rate of reentrainment was not shown to be a function of the amount of material on a street, reducing the amount of material by street cleaning might not consistently reduce particulate concentrations.

In contrast to the street cleaning studies, both of the mud carryout control studies showed significant reductions in particulate concentrations. At the construction site study, intensive manual cleaning reduced nearby concentrations by 10 to 20 $\mu\text{g}/\text{m}^3$. The area of impact of mud carryout was estimated to be about a 1000 ft radius around the site. Data from a subregional area of Seattle indicate that similar reductions in concentrations can be obtained over a large area through a comprehensive control program for mud carryout

sources such as unpaved shoulders, unpaved parking areas, and truck terminal lots.

IMPLEMENTATION OF CONTROL MEASURES

Implementation of control measures for reentrained dust will require new approaches by air pollution control agencies. Most importantly, authority and capabilities for reducing reentrained dust from streets reside with city public works departments. Air quality improvement may be of concern within public works agencies, but it would not necessarily be a consideration with high priority. Therefore, unless these agencies receive a strong directive or increased funding, only marginal changes in street cleaning or dirt and mud carryout controls can be expected. Time requirements for programming and budgeting usually preclude rapid implementation of program modifications.

Implementing a control measure for reentrained dust may also require a well-developed educational presentation. Reentrained dust, unlike a major point source, is not an obvious, visible source of particulate emissions. It would be difficult to get public or local government support for the increased costs of an expanded street cleaning program or a transportation control measure without strong documentation of the air quality impact of reentrained dust and the anticipated effect of the proposed measure.

The proposed method of implementation focuses on drafting of an administrative agreement between the state air pollution control agency and the local government. This document would formalize the approval of the city administration and establish the framework for cooperative development of the control measure, whether it is based primarily on modifications to the street cleaning program or control of dirt and mud carryout sources.

Street cleaning, at least for the level of cleaning evaluated, is still unproven as a control measure and should therefore be adopted cautiously. A pilot study incorporating proposed changes is recommended prior to any full-scale modifications of a city's street cleaning program, at least until more data on the effectiveness of improved street cleaning become available. The interest and support of the public works department are required in order for the measure to be successful. If the changes are not supported or viewed as important, the expanded cleaning program will probably not translate into an air quality improvement.

Another reason for testing street cleaning modifications on a smaller scale is that study data from one city may not be applicable in another due to great differences in street systems (storm drainage, curbs and gutters, age and type of surface, etc.) and productivities of street departments.

Mud carryout controls have a more consistent record of success, and can be readily implemented by an air pollution control regulation or ordinance for major sources such as construction sites. An administrative agreement with local governments may also be needed to control municipally-owned mud carryout sources such as unpaved shoulders and streets. The most difficult sources to encompass under a regulation are the minor, privately-owned sources such as driveways, unpaved parking areas, and storage lots.

The limited data available indicate that traffic reductions could also be effective in reducing urban particulate concentrations. Traffic reductions would probably only be considered in urban areas where a control plan requiring such reductions would be needed for carbon monoxide or oxidants.

COSTS

In most cases, either mud carryout controls or improved street cleaning (in areas where it can be demonstrated to be effective) would be much more cost-effective in reducing urban particulate concentrations than additional point source or area source controls. The costs are estimated to be on the order of \$1,000 per ug/m^3 reduction in annual average concentrations over an area of one mi^2 , and the measures can be applied somewhat selectively in those areas where particulate concentrations are highest (non-attainment areas).

1. INTRODUCTION

SCOPE OF WORK

According to several recent studies,^{*} reentrained dust from paved streets and other traffic-related emissions are major sources of suspended particulate in urban areas and are a leading cause of concentrations above the ambient air quality standards. Yet, these sources are not subject to any controls.

This document was prepared to identify control measures which can reduce the air quality impact of traffic-related particulate emissions, to compile available information on these control measures, and to report on several field studies which were done specifically to evaluate the effectiveness of control measures for reentrained dust. It also proposes procedures for planning and implementing the control measures. Finally, the document provides detailed information on the characteristics of reentrained dust and of the material found on street surfaces.

Most of the effort in this assessment of controls for reentrained dust was allocated to five field studies. Three of the field studies investigated street cleaning methods, one examined control of a mud carryout source, and the other attempted to identify the variables which affect reentrained dust emission rates. The field studies and their results are discussed in Chapter 3.

^{*} These studies are described on pages 1-3 through 1-5.

In addition, six cities were located in which potential control measures had been implemented. Particulate air quality data for time periods with and without the control programs were obtained and analyzed to determine effects on particulate concentrations. These data analyses are also presented in Chapter 3.

During the project, many public works personnel were contacted to obtain information. Cost data for street cleaning and for mud carryout controls are summarized in Chapter 4. Specific methods of reducing reentrained dust impact, developed from results of the field studies and through discussions with public works personnel, are presented in Chapter 5.

Potential regulatory approaches are discussed in Chapter 6. Existing public works and air pollution control ordinances were reviewed to uncover innovative approaches.

An extensive literature review¹ performed early in the study was relied upon to provide much of the information on characteristics of reentrained dust and material on street surfaces. These two topics are covered briefly in Chapters 1 and 2, respectively, to provide the reader with appropriate background information. More detailed presentations on reentrained dust and material on street surfaces can be found in Appendices A and B.

RECOGNITION OF THE REENTRAINED DUST PROBLEM

No references to reentrained dust from streets as an emission source were found in the literature prior to 1972. At that time, the Puget Sound Air Pollution Control Agency performed some limited sampling of reentrainment by mounting impaction plates on a trailer pulled behind the test vehicle.² Shortly thereafter, some microscopic analyses of high volume samples for Chicago and Philadelphia were reported.^{3,4}

The samples had large quantities of mineral particles which appeared to be road surface aggregate.

As the date for attainment of the National Ambient Air Quality Standards (NAAQS) approached and many metropolitan areas still had particulate concentrations well above the primary annual standard for particulate, many studies were initiated to better identify the sources contributing to the high particulate concentrations. These studies were conducted concurrently and were done independently of one another using many different methodologies--microscopy, emission inventory, statistical analysis of historical air quality data, detailed survey of the areas surrounding the samplers, additional sampling to determine concentration gradients, etc.

All of these recent studies have arrived at similar conclusions: reentrained dust from streets has an annual impact of 10 to 30 $\mu\text{g}/\text{m}^3$ at most urban sites and constitutes 10 to 50 percent of the particulate emissions in these areas. The studies are described briefly below:

- ° In a national assessment of the urban particulate problem which investigated 14 metropolitan areas, the average impact from vehicle-related emissions was found to be 15 to 23 $\mu\text{g}/\text{m}^3$ in residential areas and 22 to 30 $\mu\text{g}/\text{m}^3$ in commercial and industrial areas; at individual sites, the impact was as much as twice these amounts.⁵
- ° At 10 temporary sampling locations on sidewalks in downtown and suburban Philadelphia, microscopic analysis indicated that 50 to 90 percent of the particulate matter collected was from vehicular traffic.⁴
- ° After analyzing eight years of air quality data for Chicago, one researcher attributed 13 to 15 $\mu\text{g}/\text{m}^3$ on an annual basis at all sites to reentrained dust from vehicular traffic.⁶ A separate

study of Chicago's ambient monitoring network which employed microscopy to identify particle origin concluded that 10 to 80 percent by weight of the collected material was reentrained, much of it by auto traffic, and that 0.5 to 5 percent was automobile exhaust emissions.³

- An analysis of the Kansas City area showed that 30 to 55 $\mu\text{g}/\text{m}^3$ were contributed to annual average concentrations in areas exceeding the primary standard by reentrained dust from motor vehicles. An emission factor of 10.7 g/veh-mi was used. However, if the value of 3.7 g/veh-mi obtained from the project field studies in Kansas City were substituted, the impact from reentrained dust would be 10 to 19 $\mu\text{g}/\text{m}^3$.⁷
- An emission inventory of Nashville and Davidson County, Tennessee revealed that 50 percent of the area source emissions in this urban area in 1975 were due to reentrained dust from motor vehicles.⁸
- Preliminary data from a study conducted in New York City showed that average particulate concentrations at sites located near streets were 26 $\mu\text{g}/\text{m}^3$ higher during the 12 hours of the day with high traffic volumes than during the remaining 12 hours.⁹
- Particulate diffusion modeling of Jacksonville revealed that 10 to 20 percent of the ambient concentrations in most areas of the city were from vehicle-related emissions.¹⁰
- In business and residential areas of Phoenix, vehicle-related emissions were found to constitute 35 to 50 percent of total particulate emissions.¹¹
- Semiquantitative elemental analysis and microscopic analysis of particulate samples from the industrial area of Seattle showed an average of 39 percent of the collected material originated from motor vehicles or reentrained road dust,

with about 35 percent being attributed to reentrained dust.¹²

- ° In Colorado Springs, diffusion modeling indicated that 29 percent, or about 25 ug/m³, of the annual average concentrations in areas currently exceeding the primary standard result from reentrained dust from streets and that an additional 5 percent is contributed by motor vehicle exhaust and tire wear.¹³
- ° Particulate diffusion modeling of the Tampa Bay area showed 10 to 25 percent of the ambient concentrations in areas exceeding the primary annual standard were from vehicle-related emissions.¹⁴

If vehicle-related particulate emissions have not been identified as one of the most important source categories in any large city, this is probably because the emission inventory for that city has not been updated to include reentrained dust from traffic as a source.

CHARACTERISTICS OF REENTRAINED DUST

A brief summary of the important characteristics of reentrained dust is included here to assist the reader in interpreting data presented later in the report. Much of the information for this section was obtained during the field studies done for this project. The field study designs are shown in Appendix D and the characteristics of reentrained dust are discussed in much more detail in Appendix A.

According to precise definition, reentrained dust is only that portion of vehicle-related emissions which is thrown from the street surface by contact with vehicle tires or is induced to become airborne by the vortexes from passing vehicles. Other particulate matter is emitted directly by the vehicles: engine exhaust, wear of various parts such as bearings and brake and clutch linings, and from abrasion of

tires against the road surface. However, many of these direct emissions settle to the road surface, become part of the street surface loading, and are subsequently reentrained.

It is very difficult to distinguish in sampling whether the suspended material has been directly emitted or reentrained. It does appear from studies of total traffic-related impact that the reentrained portion is an order of magnitude greater than the direct emissions accounted for by currently available emission factors for vehicle exhaust (0.34 g/veh-mi) and tire wear (0.20 g/veh-mi).

The average vehicular emission rate calculated in the field studies from short-term downwind ambient concentrations using a line source dispersion equation was 3.7 g/veh-mi, with a standard deviation of 3.3 g/veh-mi. This was determined to be equivalent to an *initial* emission rate of 4.9 g/veh-mi with the observed average fallout rates of 14 percent at 10 m, 26 percent at 20 m, and 34 percent at 30 m from the street. A recent EPA-sponsored emission factor development study reported an average emission rate for particles less than 30 μ of 8.5 g/veh-mi, and a summary of resuspension studies concluded that the resuspension rate for particles less than 40 μ is probably in the range of 1 to 5 g/veh-mi.^{15,16}

Suspended particulate samples taken near streets in the present field studies had relatively large particle sizes--a mass median diameter of 15 μ and approximately 22 percent by weight greater than 30 μ . The samples also displayed a strong bimodal distribution, with a large percentage of the material being less than 3 μ in diameter and another large percentage in the 15 to 30 μ range.

The small particulate (less than 3 μ) was identified microscopically as primarily combustion product, while most of the large material was of mineral origin. Combustion

products (from both mobile and stationary sources) averaged a surprisingly large 40 percent of the weight, indicating that exhaust emissions may constitute a larger portion of total vehicle-related emissions than previously suspected. Mineral matter constituted an average of 59 percent of the particulate collected near streets, while biological matter and tire tread together comprised a little more than one percent. Inorganic lead was determined chemically to account for an average of one to two percent of the suspended particulate.

Four variables were evaluated to determine their effects on reentrainment--traffic volume, traffic speed, street surface loading, and wind speed. Particulate concentrations near a street were found to be fairly closely related ($r = 0.5$ to 0.8) to traffic volume within the range of traffic volumes tested. A weak inverse relationship ($r = -0.3$) between particulate concentrations and traffic speed was observed. No relationship was found between particulate concentrations and street surface loadings. The data showed that wind speed is directly ($r = 0.3$ to 0.4) rather than inversely related to particulate concentrations, indicating that the dust generating and transport effects of increased wind speed more than offset the diluting effect of the higher wind speed.

POTENTIAL CONTROL MEASURES

Prior to this study, no information was available on methods of reducing the emissions or impact of reentrained dust. Consequently, one of the initial tasks was to identify measures which could possibly reduce the amount of suspended particulate caused by reentrainment. The resulting list includes five general approaches:

- ° Improved street cleaning
 - Broom sweeping
 - Vacuum sweeping
 - Regenerative air sweeping
 - Flushing
- ° Modified snow and ice control procedures
 - Replace sand with salt or a salt/sand mixture
 - Plow instead of sand or salt
 - Remove anti-skid material as soon as possible
 - Apply less material
- ° Control of dirt and mud carryout from major sources (e.g., construction sites, truck terminals)
- ° Control of dirt and mud carryout from ubiquitous sources (e.g., unpaved parking areas, shoulders, and driveways)
- ° Reduction in traffic volumes on a street

All but the last of these measures are concerned with reducing the amount of material available for reentrainment from street surfaces. Also, all of the measures are outside the normal areas of authority of air pollution control agencies.

Each of the four types of municipal street cleaning equipment was proposed for consideration as a control measure. Broom sweepers utilize a rotating gutter broom to move material from the curb area (where most of the debris is located) into the main pickup broom and then onto a belt and into the hopper. Most broom sweepers are equipped with a water spray for dust suppression.

Vacuum sweepers use a broom to loosen and move the dirt and a vacuum system to pick it up. All material picked up by the vacuum nozzle is saturated with water on entry and passes into a vacuum chamber where it drops out of the air stream. Another type of unit similar to the vacuum sweeper, the regenerative air sweeper, is designed to blast dirt from

the road surface into the hopper, with part of the air stream being recycled and part vented through the dust separation system.

Street flushers consist of a water supply tank mounted on a truck, a pump to provide pressure, and three or more nozzles to spread the water in directional sprays. The nozzles are individually controlled and are usually placed so that one is directed across the path of the flusher and the two others are pointed out toward the gutters. Flushing is used primarily to displace dirt from the travel lanes of the street into the gutter. The volume of water is not sufficient to transport the accumulated material to the nearest drain. Flushing is also presumed to reduce reen-trainment for a short period of time by its wetting action.

None of the available street cleaning equipment was designed for air pollution control purposes. Future equipment could be more effective because of such design changes.

Specific measures which can be employed to control dirt and mud carryout by trucks from locations such as construction sites and truck terminals include paving (for permanent-traffic areas), use of coarse gravel or fragmented brick, chemical stabilization, requiring trucks to have tire scrapers, wheel washes at construction site exits, and required covering or wetting of loaded trucks. Very little can be done to prevent the trackout that occurs during excavation. Contractors can be required to clean access streets manually or with mechanical sweepers while excavation is in progress.

Another source of mud on streets near construction sites is runoff. This source can be controlled by measures such as temporary grading, on-site retention, compacting of stabilization, revegetation, and limiting the acreage of cleared area that can remain exposed.

A large number of unpaved areas adjacent to streets (e.g., parking lots, road shoulders, driveways, industrial

and warehouse lots) can increase the amount of material on street surfaces. Control of these small sources can be achieved by requiring paving, oiling, or seal coating to limit trackout and to reduce directly-emitted dust.

2. MATERIAL ON STREET SURFACES

Before control measures can be developed to reduce the amount of material deposited on streets, it must first be determined where most of the material found on street surfaces originates. Also, prior to analysis of the effect of improved street cleaning on dust reentrainment rates, it would be desirable to know the relative amounts of material removed from streets by cleaning, reentrainment, and other removal processes. Therefore, the purposes of this chapter are to identify the various deposition and removal processes which determine the amount of material on a street surface and to attempt to quantify typical rates at which each of these processes operate.

Most of the data used to estimate deposition and removal rates was obtained from the literature rather than from analysis of street loading samples taken during the field studies to provide data for this document. References and estimating procedures are presented in Appendix B.

The street loading measured at any time represents the net balance of all the deposition and removal processes, some acting almost continuously, some intermittently, and some (e.g., street sanding) on only a few occasions per year. These are shown schematically in Figure 2-1.

Two of the primary removal mechanisms, rainfall and street sweeping, are intermittent. To the extent that deposition exceeds removal rates between these intermittent processes, material accumulates on streets.

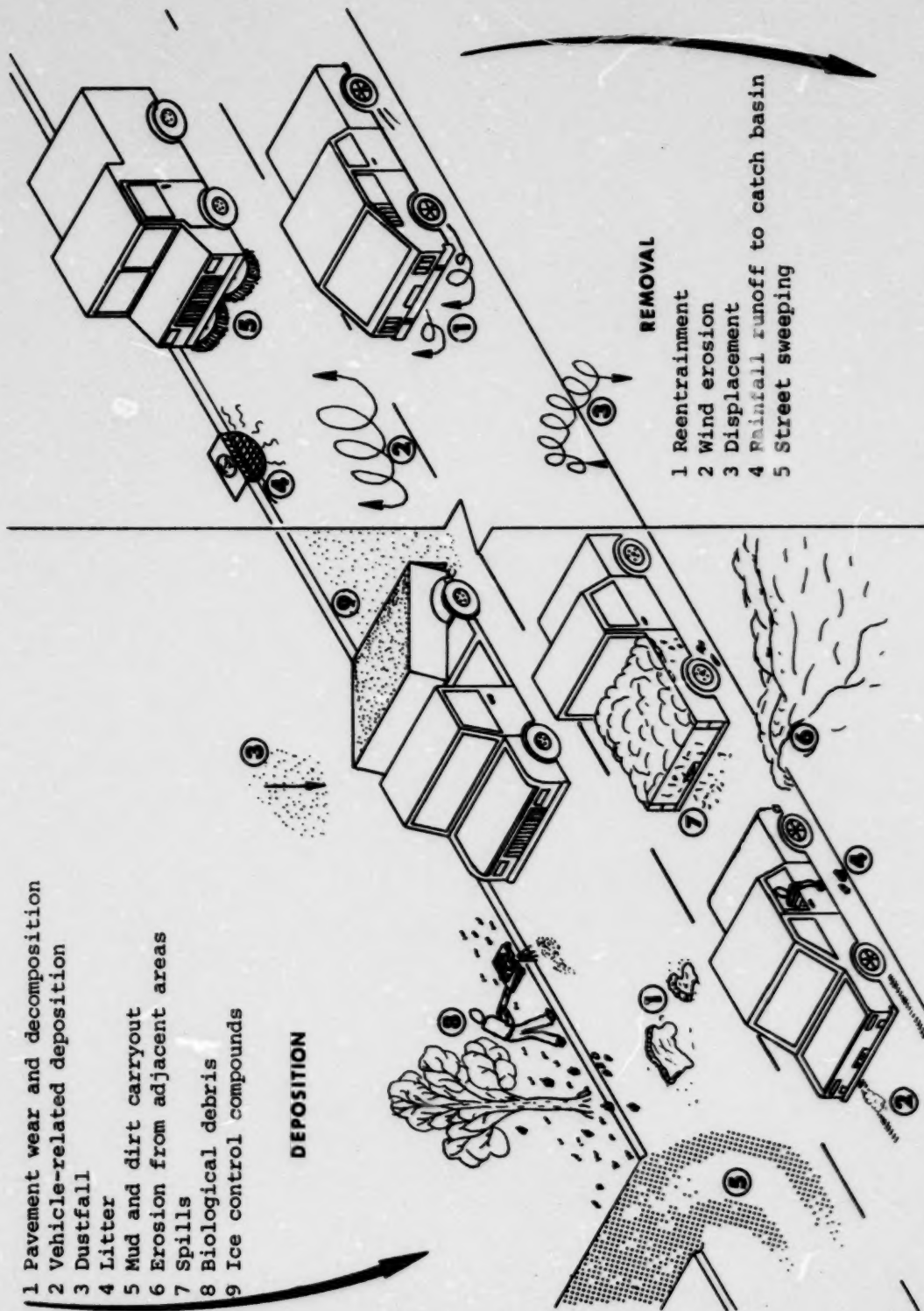


Figure 2-1. Deposition and removal processes.

"Typical" annualized deposition rates for nine processes identified in the literature as significant contributors to street surface loadings are presented in Table 2-1. It should be emphasized that these values are only order-of-magnitude estimates and should not be considered representative of deposition on any single day on a particular street. All of these processes except application of ice control compounds occur at a fairly constant rate with time.

In contrast, most removal processes are intermittent and their rates are primarily a function of the amount of material on the street at the time they occur. Estimates of typical rates for the five major processes for removal of material from streets are shown in Table 2-2.

Some of the characteristics of the material found on street surfaces influence removal rates:

- ° Most of the material is too large to become directly airborne, with the <44 μ fraction averaging 6 and 10 percent in two different investigations.
- ° Most of the material collects within a foot of the curbs rather than being uniformly distributed across the streets.
- ° Normally, more than 95 percent by weight of the material is inorganic, with a bulk density of about 1.6 g/cm³.

Table 2-1. DEPOSITION PROCESSES

Source	Constituents	Typical deposition rate, lb/curb-mi/day	Range, lb/curb-mi/day
1. Mud and dirt carryout	Soil from construction sites, unpaved parking areas, etc.	100	Extreme
2. Litter	Cans, bottles, broken glass, cigarette butts, plastic, other debris	40	Extreme
3. Biological debris	Leaves, grass clippings, sticks, animal droppings, insect parts, etc.	20	Extreme
4. Ice control compounds	Sand, salt, cinders, calcium chloride	20	0-60
5. Dustfall	Atmospheric fallout	10	2-25
6. Pavement wear and decomposition	Asphalt, cement, aggregate, expansion joint compounds and fillers	10	5-150
7. Vehicle-related			
-Tire wear	Rubber	10	6-50
-Brake and engine component wear	Metals, lubricants, brake and clutch linings	5	2-25
-Settleable exhaust	Combustion products, fuel additives	2	1-10
8. Spills	Sand, dirt, chemicals	No data; est <2	
9. Erosion (runoff and blowing) from adjacent areas	Soil	20	Extreme
Total		240	

Table 2-2. REMOVAL PROCESSES

Process	Typical removal rate, lb/curb-mi/day	Assumptions incorporated
Reentrainment	100	For 10,000 ADT; net removal rate = 4.5 g/VMT
Displacement	40	Estimated from dustfall rate just beyond curb
Wind erosion	20	Force of same magnitude as reentrainment, but only operative 20% of time
Rainfall runoff	50	Removal efficiencies of 50% for rain of 0.1-0.5. and 90% for rain of >0.5 in.
Sweeping	35	Average efficiency of removal = 50%; weekly clning

3. TESTING THE EFFECTIVENESS OF CONTROL MEASURES

Several of the potential control measures identified in Chapter 1 were investigated to determine their impacts on particulate air quality as measured with high volume samplers. There are three types of evaluations included in this chapter:

- project field studies specifically designed to quantify the effect of a control measure (performed by PEDCo-Environmental in study areas in Kansas City and Cincinnati);
- evaluations in which a control measure in the form of a municipal program or short-term test was implemented in a city and available air quality data were collected after-the-fact to estimate the air quality impact of the program; and
- estimates based on theoretical approaches for control measures which were not subjected to field studies.

Each of the four project field studies^{*} and six program evaluations is presented as a separate subsection. The results of all these evaluations are then summarized and collective estimates of control efficiencies made at the end of the chapter.

More information on the four project field studies can be found in Appendix C.

* The fifth project field study investigated variables which affect reentrained dust emission rates. Since it did not evaluate a specific control measure, this field study is not discussed in this chapter. Its study design is described in Appendix C.

PROJECT FIELD STUDIES

Street Cleaning in Kansas City, Missouri

Study Design - The primary purpose of this study was to determine the effect of alternative street cleaning methods on particulate air quality in the area being cleaned. Two street cleaning methods were evaluated: broom sweeping and flushing. Streets in the study area were cleaned once weekly for a period of one month with each type of equipment. Also, the streets were not cleaned for a one-month period. Particulate concentrations were measured daily at eight sampling sites in the study area for the entire three months. Average concentrations associated with each cleaning period were compared after being adjusted to account for differences in regional particulate concentrations during the three periods.

The four by seven block study area was located in a commercial/warehousing district just south of Kansas City's central business district. Almost all the streets in the area have average daily traffic (ADT) volumes of 4,000 to 15,000 vehicles.

Results and Conclusions - Particulate concentrations were relatively uniform at the eight sites on any one day in comparison with the day-to-day variations at all the sites. The plot of daily data also showed a consistent weekly pattern of concentrations, with low concentrations on weekends, slightly higher concentrations on Mondays, and high concentrations on other weekdays. The weekly pattern was attributed to differences in daily traffic in the study area.

Average concentrations during each of the cleaning periods are shown in Table 3-1. The flushing period was only three weeks due to the early onset of cold weather.

Table 3-1. COMPARISON OF PARTICULATE CONCENTRATIONS IN KANSAS CITY DURING THREE CLEANING PERIODS

Site no.	Geometric mean concentration, ^a ug/m ³			Relative rank of periods by geom. mean ^b		
	Broom sweep 09/13-10/10	Flushing 10/17-11/07	No cleaning 11/08-12/12	High	Med	Low
<u>Sites in cleaning area</u>						
A-1	107.4	98.0	125.6	N	B	F
A-2	115.6	107.6	140.8	N	B	F
A-3	104.4	90.0	111.7	N	B	F
A-4	113.4	98.6	126.9	N	B	F
A-5,6	113.4	97.3	130.8	N	B	F
A-7	149.8 ^c	105.4	134.2	B	N	F
A-8	114.5	94.4	114.5	N	B	F
Avg.	116.2	98.6	126.0	N	B	F
<u>Control sites</u>						
C-13	52.9	59.0	71.1	N	F	B
C-14	54.0	59.6	72.4	N	F	B
C-15	100.7	84.8	89.2	B	N	F
Avg.	66.0	66.8	77.1	N	F	B
15 Regional stations	84.1	74.6	92.5	N	B	F
"A" sites	32.1	24.0	33.5			
- Reg. sites						
"A" sites	50.2	31.8	48.9			
- "C" sites						

^a Calculated using every other day sample values.

^b B = Broom sweeping
F = Flushing
N = No cleaning

^c Interference during sampling period from local street repair work.

This added an extra week to the no cleaning period. The unadjusted data indicated that air quality was best with flushing, next best with broom sweeping, and worst when there was no cleaning. When the average concentrations for the three periods were adjusted to account for weather-related and seasonal variations between periods, the apparent difference between concentrations during the broom sweeping period and with no cleaning was eliminated (or broom sweeping showed no reduction in particulate concentrations). However, the flushing period still showed 8 to 18 ug/m^3 (geometric mean) lower concentrations after adjustment for external differences in air quality.

Three samplers located in suburban areas five to six miles from the study area were used to provide a comparison of concentrations uninfluenced by the street cleaning during the three periods. Also, concentrations measured during the three periods at 15 high volume samplers in the regional network were used for a secondary comparison. Sampling was every sixth day at the regional network sites versus daily in the study area.

Rainfall obviously reduced concentrations on days when it occurred. In the Kansas City study area, the average reduction in concentrations on days with 0.1 inch or more of rain was 28 ug/m^3 . However, on the first day after a rain only a minimal residual effect was observed and on subsequent days no residual effect was noted. A similar impact from rainfall has been reported for other cities.⁵

Days with flushing in Kansas City inexplicably showed higher than average concentrations, although concentrations on the first days following flushing were lower than average. The characteristic change in particulate concentrations following broom sweeper cleaning in Kansas City was a moderate increase on the day of cleaning, a definite reduction on the day after cleaning, and then sharply higher concentrations for the next few days.

Street Cleaning in Cincinnati

Study Design - The purpose and approach for this study were the same as for the Kansas City street cleaning study--a comparison of particulate concentrations in a five by seven block area during periods with different street cleaning methods. In Cincinnati, three cleaning methods (flushing, broom sweeping, and vacuum sweeping) were evaluated for one month each, plus there was no street cleaning for a non-continuous one-month period. The cleaning cycles were irregular, but consistent from one month to another: the streets were cleaned early in the first week of each period, not at all during the second week, twice during the third week, and once in the fourth week. Coincidentally, there were three days of rain between the first and second cleaning during each period, so there were no times longer than a week without cleaning or natural washing of the streets and several periods with cleaning at three- or four-day intervals.

As in the Kansas City study, average concentrations for each of the cleaning periods were adjusted to account for differences in particulate concentrations between the periods due to factors other than street cleaning (primarily weather-related and seasonal variations).

The Cincinnati study area was located in a primarily residential area with one commercial street, Hamilton Avenue. This street has an ADT of 17,700 but most other streets in the area have less than 1,000 vehicles per day. Seven samplers were placed in the study area and operated daily.

Results and Conclusions - Concentrations in the Cincinnati study area were much lower than in Kansas City, and the impact from traffic-related emissions appeared to be much less. No distinct weekly pattern of concentrations was seen. Differences between weekday and weekend concentrations were not expected, since traffic data indicated that

traffic volumes were approximately the same for weekdays and weekends.

Average concentrations for each of the sampling periods are shown in Table 3-2. Without considering variations between sampling periods due to weather-related factors, air quality was best during the month of broom sweeping, nearly the same during the months with flushing and vacuum sweeping, and worst when there was no street cleaning.

There was no sampling site operated daily outside the cleaning area that could be used to estimate differences in air quality for the four periods. To provide some measure of the variation in external air quality, concentrations at seven regional control agency sites within a four mile radius were determined for the four periods. The sampling schedule at these sites was every sixth day. As indicated by the data in Table 3-2 for the seven sites, the high concentrations during the no cleaning period occurred outside the study area, too.

According to the air quality data, broom sweeping was the most effective cleaning method. Concentrations averaged 6 to 20 ug/m^3 less during this period than during the other three periods regardless of whether data from sites outside the study area were used to adjust for the differences in concentrations between periods.

The average concentrations for the month of flushing did not indicate a significant reduction by use of this cleaning method, although a plot of concentrations in the Cincinnati study area as a function of time since flushing showed that concentrations were 16 ug/m^3 lower on the days when the flushing was done and 4 ug/m^3 less than average on the first day after flushing. The air quality impacts from flushing and broom sweeping in the Cincinnati study were reversed from what they were in the Kansas City study.

Table 3-2. COMPARISON OF PARTICULATE CONCENTRATIONS IN CINCINNATI
FOR FOUR CLEANING PERIODS

Site no.	Geometric mean concentration, ug/m ³				No clean 4 weeks			Relative rank of periods by geom. mean ^a		
	Flushing 09/20-10/17	Broom sweep 10/18-11/14	Vacuum 11/22-12/17					High	2nd	Low
<u>Sites in cleaning area</u>										
2-B	65.0	62.0	72.6		78.2		N	V	F	B
2-T	59.0	53.3	62.1		71.8		N	V	F	B
3-B	62.1	53.4	60.8		73.4		N	F	V	B
3-T	58.8	48.3	53.0		68.1		N	F	V	B
1	57.3	52.7	60.0		74.9		N	V	F	B
4	49.5	44.2	47.0		67.5		N	F	V	B
5	56.3	49.4	53.4		67.4		N	F	V	B
Avg.	58.0	51.7	57.9		71.5		N	F	V	B
<u>Control sites</u>										
7 Regional sites	58.7	61.4	54.5		73.7		N	B	F	V
<u>Study area sites</u>										
- Reg. sites	-0.7	-9.7	3.4		-2.2					

^a F = Flushing
B = Broom sweeping
V = Vacuum cleaning
N = No cleaning

Taken at face value, the air quality data from the study area and from surrounding sites indicated that vacuum sweeping of streets increased concentrations about 5 ug/m^3 compared to no cleaning. This was thought to be an anomaly resulting from the noncorresponding sampling schedules for the two data sets being compared--daily sampling in the study area and every sixth day for the sites outside the study area. Nevertheless, comparison of concentrations during the vacuum cleaning period with those from other cleaning periods could only lead to the conclusion that this method was not effective in reducing particulate concentrations in the study area.

This finding is unexpected considering the demonstrated efficiency of the vacuum units in removing small size particles from street surfaces and their overall street cleaning efficiency in the study area.¹⁷ As shown in Table 3-3, the vacuum sweepers had removal efficiencies consistently higher than the broom sweepers. These cleaning efficiencies were determined from street loading measurements taken before and after each cleaning operation.

Table 3-3. CLEANING EFFICIENCY OF STREET CLEANING METHODS

Type of cleaning	Date/Location	Curbs and traffic lanes	Percent removal of material					In traf- fic lanes only
			Particle size range, um					
			<44	44-106	106-841	>841		
Broom	Sep 22 K.C.	41.8	-77 ^a	-136	62	65	52.1	
Broom	Sep 29 K.C.	10.9	-11	-15	11	45	33.7	
Broom	Oct 20 CINC	40.4	1	34	52	30	-109.0	
Broom	Nov 03 CINC	57.5	63	80	62	1	n.a.	
Broom	Nov 06 CINC	24.2	8	24	23	28	n.a.	
Broom	Nov 10 CINC	60.9	9	40	52	78	n.a.	
Flush	Oct 20 K.C.	-2.6	-38	-13	3	-2	43.6	
Flush	Nov 02 K.C.	n.a.	90	90	-171	n.a.	58.4	
Flush	Oct 06 CINC	1.3	29	25	7	-54	34.9	
Flush	Oct 09 CINC	5.9	-1	16	-3	20	-51.0	
Flush	Oct 13 CINC	18.4	21	25	69	1	-55.6	
Vacuum	Nov 24 CINC	62.1	34	62	59	71	n.a.	
Vacuum	Dec 07 CINC	70.4	79	86	75	32	n.a.	
Vacuum	Dec 11 CINC	60.0	-85	2	60	73	n.a.	
Vacuum	Dec 15 CINC	53.2	-17	48	63	65	n.a.	

^a Negative values indicate an increase in material following cleaning.
n.a. = data to calculate this value not available.

Street Cleaning in Residential Areas

Study Design - This study was intended to show whether the regular use of vacuum sweepers on low traffic density residential streets results in improved particulate air quality.

A high volume sampler was located in the center of the City of Westwood, a residential suburb of Kansas City. Streets and gutters in Westwood appear visibly clean at all times. All the streets in the city are cleaned about once a week with a vacuum sweeper, while surrounding communities use broom sweepers. Particulate concentrations were also measured on the same sampling schedule (every other day) in the adjacent community of Roeland Park, where street cleaning is done less frequently with mechanical broom sweepers and some of the streets are not curbed and guttered. An effort was made to place the two samplers in comparable exposures: both were located atop one story, flat roof buildings at distances of about 150 feet from the nearest street. There are no particulate point sources in either community, so any reduction in ambient concentration at the Westwood site should provide a measure of the impact of vacuum street sweepers on subregional particulate air quality.

Results and Conclusions - The difference in daily concentrations for the sampling sites in Westwood and Roeland Park for the 43 sampling days indicated that there was no significant difference in air quality at these two locations. The data are shown in Table 3-4. A t-test showed an average difference of 0.1 ug/m^3 and a corresponding t value of 0.08 compared to the calculated t value (at 95 percent confidence) for rejecting the null hypothesis of 2.04.

Vacuum street cleaning appears to provide excellent removal of material from residential street surfaces, but it was concluded that optimal street cleaning in such a low traffic density area does not improve air quality because there is not a significant contribution from reentrained dust.

Table 3-4. PARTICULATE CONCENTRATIONS AT
WESTWOOD AND ROELAND PARK SITES

Date	Particulate concentration, $\mu\text{g}/\text{m}^3$		
	Westwood	Roeland Park	Difference
09-12	60.5	60.1	+0.4
09-14	69.6	77.3	-7.7
09-17	85.4	95.2	-9.8
09-19	39.5	37.7	+1.8
09-21	57.1	53.0	+4.1
09-23	59.6	65.5	-5.9
09-25	56.8	62.4	-5.6
09-27	43.0	44.3	-1.3
09-29	51.3	58.6	-7.3
10-01	77.9	61.6	+16.3
10-03	47.6	50.3	-2.7
10-05	28.3	29.6	-1.3
10-07	43.4	48.9	-5.5
10-09	56.4	47.0	+9.4
10-11	45.5	48.4	-2.9
10-13	81.9	75.6	+6.3
10-15	207.1	200.6	+6.5
10-17	65.5	72.7	-7.2
10-19	43.8	39.0	+4.8
10-21	52.5	50.9	+1.6
10-23	36.4	36.7	-0.3
10-25	58.3	72.3	-14.0
10-27	n.d.	n.d.	
10-29	45.1	47.9	-2.8
10-31	86.5	75.0	+11.5
11-02	64.8	71.1	-6.3
11-04	80.0	74.7	+5.3
11-06	79.2	77.3	+1.9
11-08	77.5	79.6	-2.1
11-10	118.3	107.4	+10.9
11-12	104.0	77.8	+26.2
11-14	62.8	66.0	-3.2
11-16	(45.0)	n.d.	
11-18	115.4	115.2	+0.2
11-20	83.2	84.6	-1.4
11-22	55.7	45.7	+10.0
11-24	54.9	50.2	+4.7
11-26	52.2	60.5	-8.3
11-28	36.5	38.8	-2.3
11-30	59.9	64.7	-4.8
12-02	82.2	93.2	-11.0
12-04	126.2	113.9	+12.3
12-06	56.6	60.5	-3.9
12-08	64.6	67.1	-2.5
12-10	68.7	77.6	-9.1
12-12	n.d.	(57.2)	
Average	68.4	68.3	+0.1

Mud Carryout Control At A Construction Site

Study Design - This study was designed to evaluate the effect on air quality of potential control measures for reducing the amount of material deposited on streets from a major mud carryout source. The control methods evaluated were: (1) frequent cleaning of the access area with municipal street cleaners; (2) manual cleaning of the access area at intervals with broom and shovel; and (3) immediate manual cleaning of tracked material. A one-time tracer study was also conducted at this site to determine how far material is distributed from its initial carryout point by traffic on the nearby streets.

Four high volume samplers were placed at three locations near a building construction site in Kansas City. Samplers were located in both directions along the access street from the construction site entrance to ensure that the impact of mud carryout would be monitored even if the mud tracking was concentrated in one direction. The effectiveness of each control measure was determined by comparing air qualities during three cleaning periods with air quality during the no control period.

Results and Conclusions - Particulate air quality in the vicinity of the construction site was greatly affected by excess reentrained dust caused by material tracked from the site. Concentrations were 40 to 60 $\mu\text{g}/\text{m}^3$ (geometric mean) higher at the four sites in the study area than at the closest sampler locations in the regional network. It did not appear that much of this impact was from fugitive dust emitted directly from the construction site.

Average concentrations at each of the sites during the periods with different mud carryout controls are summarized in Table 3-5. Comparison of particulate levels during the

Table 3-5. PARTICULATE CONCENTRATIONS ASSOCIATED WITH
DIFFERENT MUD CARRYOUT CONTROL MEASURES

Control measure	Geometric mean concentration, $\mu\text{g}/\text{m}^3$			
	Minimal cleaning (no control)	Manual cleaning at intervals	Municipal cleaning	Continuous manual cleaning
Time period	09/12-10/14	10/15-10/24	10/25-10/31	11/01-12/10
No. of samples	15	4	4	21 ^a
Sampling site				
B9 ^b	108.7	112.0	118.8	108.1
B10	132.3	118.4	135.7	119.8
B11	127.5	119.9	191.8	120.0
B12	124.4	106.8	142.9	104.6
Ranking by air quality	3	2	4	1
Average of 15 regional net- work sites	84.1	78.5	74.9	89.6

^a Only 7 samples for site B10.

^b Directional sampler for southerly wind direction
(upwind of access street); concentrations may not
agree well with other data.

different control periods revealed that concentrations were lowest when the access area had intensive manual cleaning, next lowest when manual cleaning was done intermittently, third lowest during the no control period, and highest when municipal street cleaning equipment was used along the access street. Adjustment of these concentrations to account for differences in regional air quality during the four periods, as explained in the sections describing the Kansas City and Cincinnati street cleaning studies, would not change the order of the periods. In fact, it would increase the differences in concentrations associated with the different control alternatives. It has been estimated from the data in Table 3-5 that 10 to 20 ug/m^3 reduction in concentrations at the samplers, or about 30 percent of the total impact from mud carryout at the construction site, can be achieved by immediate cleaning of the access street(s) after material is deposited on it. It appears that about half that reduction can be obtained by intermittent (i.e., daily) manual cleaning of the access street. The results from the municipal street cleaning period indicate that flushing or watering in the access area may be counterproductive.

The tracer study showed that the distance of tracking is very irregular and seems to depend on the relative traffic volumes on different streets carrying traffic away from the mud carryout source. The major impact area for reentrained dust is probably confined to a distance of 1000 ft along the primary access streets.

ASSESSMENT OF OTHER STUDIES

New York-New Jersey

Study Design - The New Jersey State Bureau of Air Pollution Control recently conducted a two year field study to characterize the particulate material resuspended from road surfaces within a large city. Sampling was conducted at two different sites--nine months in Newark and fifteen months in Brooklyn--both in commercial/business districts.

High volume samples were taken for sequential four-hour periods (six samples per day) on most days during the two years at locations four meters above street level and three meters back from the curb. For the four-hour periods concurrent with high volume samples, measurements of precipitation, traffic volume, average wind speed, resultant wind direction, temperature, and average carbon monoxide concentration were also taken.

On 15 days during the study, the streets were cleaned by flushing at 5:00 a.m. The flushing was usually done on two to three consecutive days, thus creating intensive short-term cleaning periods with extensive noncleaning periods. (Days of street cleaning in Newark were November 6, 7, and 19, 1974 and in Brooklyn were September 2, 3, 4, 5, 10, and 11, November 24, 25, 26, and 28, December 2 and 3, 1975).

Analysis of Air Quality Data - Average concentrations for each of the four-hour periods on days with flushing were compared with average concentrations for the same time periods on days with no cleaning. No attempt was made to comprehensively account for differences in meteorological conditions on days with flushing compared with the other days, but it was noted that no precipitation occurred on any of the 15 days with flushing and that wind speeds were

unusually high (18 mph) for only one of the four-hour periods on these days. Therefore, it was concluded that concentrations on flushing days were not biased downwind by unusual meteorological conditions.

A similar comparison of average concentrations on the first day after flushing (when this day was not another flushing day) with average concentrations on noncleaning days was attempted. Data were available for only three such days, one of which was a Saturday. Therefore, this comparison was felt to be of limited value.

Results and Conclusions - As shown in Figure 3-1, particulate concentrations near the streets are consistently lower on days with flushing or days after flushing than on noncleaning days. The average reduction on days with flushing was 16.1 ug/m^3 , or 15.7 percent.

The limited data from days after flushing would indicate even greater reduction in particulate concentrations than on the days of flushing. However, this anomaly was attributed to inadequate sample size.

The diurnal variation in particulate concentrations is closely related to traffic patterns on the nearest street ($r = 0.92$), as shown in Figure 3-1. This relationship between ambient concentrations and traffic volume has been found in all field studies where the two variables have been measured simultaneously for short-term periods.

This study, performed under relatively controlled conditions and with detailed data for short-term time periods, shows a definite reduction in ambient concentrations as a result of flushing. Reductions on the day of flushing are of the same magnitude as those observed in the Cincinnati street cleaning study (16.1 ug/m^3 in New York-New Jersey vs 15.8 ug/m^3 reduction in Cincinnati).

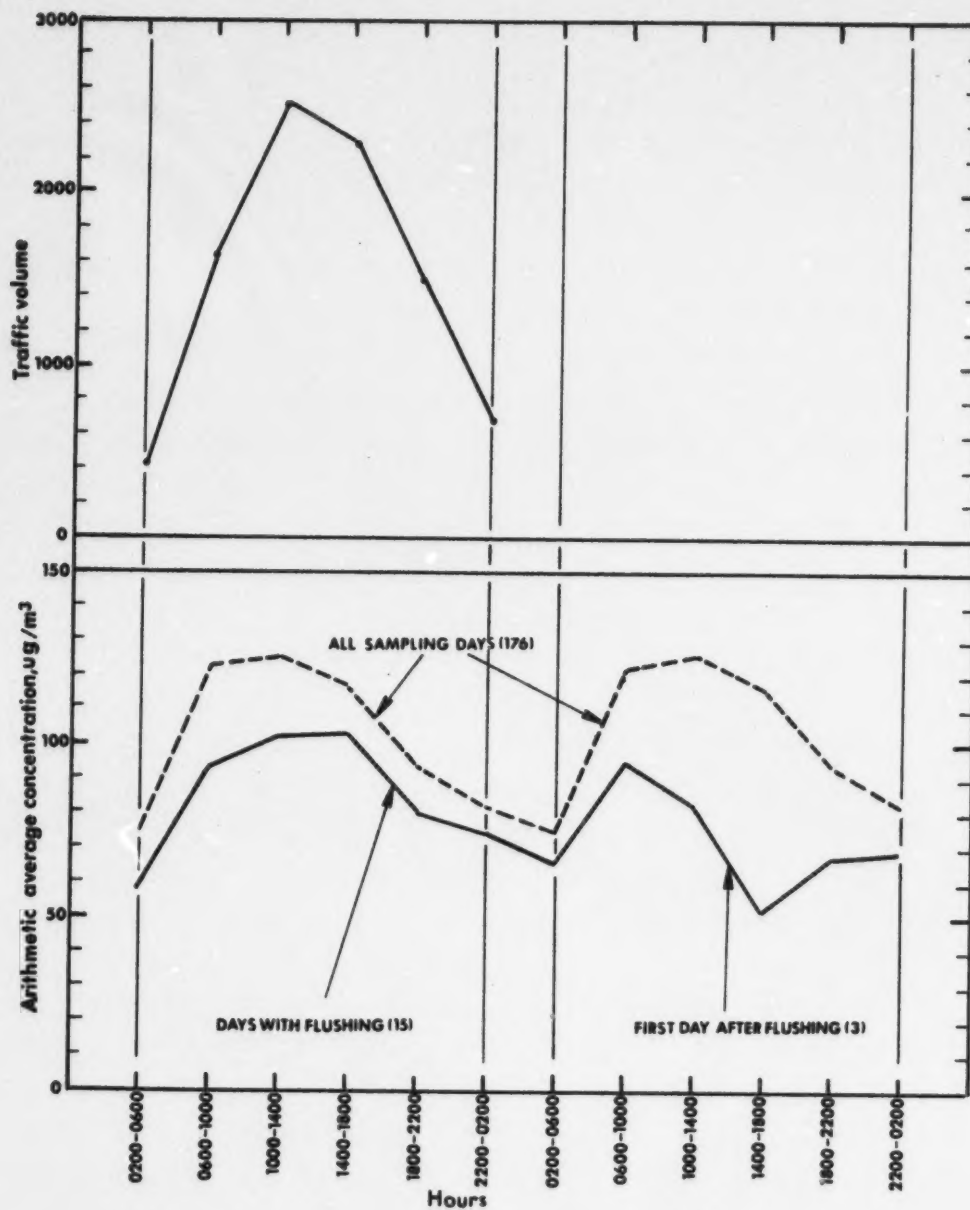


Figure 3-1. Comparison of particulate concentrations on days with flushing with average concentrations, New York-New Jersey.

Kansas City, Kansas

Street Cleaning Program - Streets in Kansas City, Kansas have been cleaned with broom sweepers in past years. Frequency of cleaning was daily in the central business district, once a week on major streets and in industrial areas, and once a month in most residential areas. Beginning in early 1976, the city initiated a street flushing program in which the streets were flushed on the same schedule on which they were cleaned with broom sweepers, with the flushing operation following the sweeping. The new program was actively implemented during the spring and summer months but was curtailed in the fall as concern over the municipal budget became a major election issue.

Analysis of Air Quality Data - The change in the street cleaning program should be detectable on ambient concentrations in Kansas City, Kansas since it was implemented throughout the city. There are three sampling stations in the regional network that have been operating without change in location in Kansas City, Kansas for the past four years. The 1976 concentrations by quarter at each of these sites were compared to the averages for the previous three years (when no flushing was done) to determine the improvement in air quality associated with the flushing. The changes in air quality in 1976 in Kansas City, Kansas were compared with corresponding changes in concentration at other urban and suburban locations in the metropolitan area (where no changes in street cleaning had occurred during 1976).

Results and Conclusions - Air quality in Kansas City, Kansas improved over previous years during the first and second quarters of 1976. In the third quarter, concentrations at

the three sites were the same as in previous years. Particulate concentrations were substantially higher during the fourth quarter, as summarized below:

Location	No. of sampling sites	Reduction in particulate concentration in 1976 from previous 3 years' average, ug/m ³			
		1 qtr	2 qtr	3 qtr	4 qtr
Kansas City, Kansas	3	5	3	0	-14
Remainder of metro area	12	7	9	-3	-20

Particulate concentrations in the remainder of the Kansas City metropolitan area were also lower than normal during the first two quarters and showed essentially the same deviation from previous years' readings as the Kansas City, Kansas sites for all four quarters. Therefore, street flushing in the subregional area where it was performed does not appear to have produced an obvious change in air quality relative to the rest of the region.

Charlotte, North Carolina

Street Cleaning Program - Starting in 1973, Charlotte began phasing out mechanical broom sweepers and began replacing them with regenerative air units, which are similar in operation to vacuum sweepers. By 1976, this replacement program was complete and all downtown and arterial streets are now cleaned with regenerative air sweepers and then flushed. The frequency of cleaning is daily in the downtown areas and twice per week on all arterials. The downtown cleaning is also supplemented by manual sweeping during the day.

Analysis of Air Quality Data - The improvement in the street cleaning program should be detectable in the trend of air quality at urban sites in Charlotte. Under this assumption, air quality data were obtained for urban sites in Charlotte (Mecklenburg County) for the years 1971 through 1976. For purposes of comparison, data were also obtained for suburban and rural sites in Mecklenburg County where the impact from reentrained dust and street cleaning would be minimal. The latter sites should not show a change as a result of the improved street cleaning program.

Results and Conclusions - The trends in air quality presented in Figure 3-2 show that air quality at the urban sites has improved significantly during the period of the change in the street cleaning program, whether all high volume sampler sites or only selected sites considered to be more representative of such regional air quality are used. However, a comparable improvement in air quality has also occurred at the suburban and rural sites in Mecklenburg County during this period. Further investigation of the observed trends revealed that point source emissions in

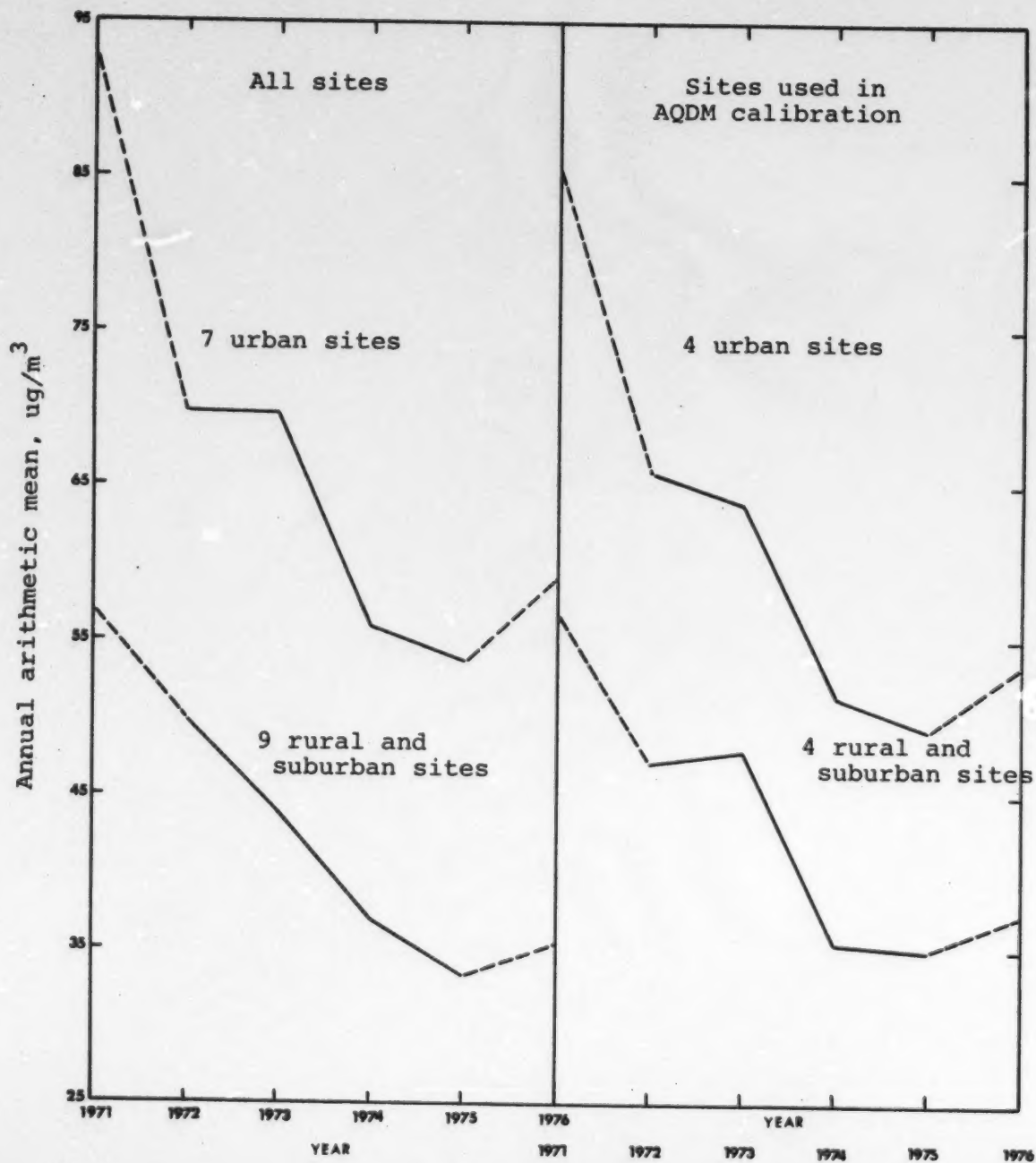


Figure 3-2. Change in average particulate concentrations in Charlotte area.

Mecklenberg County were reduced from 35,286 ton/yr in 1973 to 5,416 ton/yr in 1975. This reduction in point source emissions could certainly explain some of the uniform reduction in ambient particulate concentrations throughout the county.

Due to the parallel decreases in particulate concentrations in Charlotte at urban and rural sites, the substantial improvement in air quality cannot be attributed to the change in street cleaning techniques. It is not likely that the effect on air quality of the street cleaning improvements would be uniform over the entire metropolitan area.

Chicago, Illinois

Study Design - The Departments of Environmental Control and Streets and Sanitation in the City of Chicago conducted a one-month study in May 1974 to evaluate the effect of street sweeping frequency on particulate air quality. Four high volume samplers were located in different blocks of State Street in the downtown area. All were mounted on utility poles just back from the curb at 14 ft height. A control site less affected by vehicle-related emissions was operated about four blocks away in Grant Park. The samples were taken for 24 hours on five days a week (weekdays).

During the study period, State Street was swept daily north of Monroe (in front of sites 1 and 2) and every other day south of Monroe (in front of sites 3 and 4). All other aspects of the street cleaning were the same for both sections of the street. Traffic volumes are fairly uniform along State Street, so it was assumed that concentrations would be equal at the four sites in the absence of the different street cleaning frequencies.

Analysis of Air Quality Data - Average concentrations at sites 1 and 2 were compared with those for sites 3 and 4 to determine whether daily sweeping reduced particulate concentrations. Also, the impact of vehicle-related emissions at sites 1 through 4 was estimated by comparison of their average concentrations with those from site 5. The sampling data are summarized below:

Site	Location	Particulate concentration, ^a ug/m ³		
		Average	High	Low
1	State and Randolph	111	192	17
2	State and Madison	107	163	62
3	State and bet. Adams/ Monroe	105	173	56
4	State and Jackson	104	170	64
5	Grant Park	52	90	15

^a 24 days of data between 4-29-74 and 5-31-74.

The relative concentrations on cleaning and noncleaning days at sites 3 and 4 could not be determined because the daily data were not available and there was no record of the exact days that the sweeping was done on the southern portion of State Street.

Results and Conclusions - The impact of vehicle-related emissions on concentrations along State Street was estimated to be at least 55 ug/m^3 (arithmetic mean), this value assuming no vehicular contribution to concentrations at the Grant Park site. The great importance of vehicle-related emissions on measured concentrations was confirmed by microscopic examination of several of the samples which all showed the following percent compositions by weight:

calcite	>25	auto exhaust	5-25
quartz	.5-5	tire rubber	.5-5
clay and	<5	asphalt	<.5
humus		all other	<14

The microscopists concluded that most of the calcite was reentrained from street surfaces or from pavement wear.

At both sites with daily sweeping, concentrations were slightly higher than at the sites with sweeping every second day. Although concentrations at the four sites were so close that statistically they might not be different than zero (this could not be checked without the raw data), there was certainly no air quality benefit from daily sweeping versus sweeping every second day.

Twin Falls, Idaho

Study Design - During the summer of 1973, GCA Corporation conducted an intensive field study of suspended particulate in Twin Falls, Idaho.¹⁸ High volume samplers were operated for 91 consecutive days at nine different locations in the Twin Falls area--three in the downtown area, four in suburban locations, and two in rural areas. Meteorological data on an hourly basis were collected for the entire three-month period. There are no major particulate point sources in Twin Falls, but average concentrations above the primary standard were recorded at five of the nine sites.

Streets in the downtown area were flushed and swept weekly on Mondays (and Tuesdays if not completed on Monday). The broom sweeper was preceded by the flusher. Suburban areas in Twin Falls were cleaned on an irregular schedule and there was no street cleaning within a mile of either of the rural sampling sites.

Analysis of Air Quality Data - Since streets were cleaned weekly during the entire sampling period, the effect of street cleaning on air quality could best be determined by observing the variation in concentrations with time since cleaning. Average concentrations by day of the week for the three downtown sites (weekly cleaning) and the two rural sites (no cleaning) are shown in Figure 3-3. Concentrations at suburban sites (irregular cleaning) were not investigated because they could not be equated with days since cleaning.

Results and Conclusions - Concentrations at the three downtown sites on Mondays, the day the streets were cleaned, were lower than on any other week day. Lower concentrations on Saturdays and Sundays can be attributed to less traffic on these days. The weekly variation in concentrations at

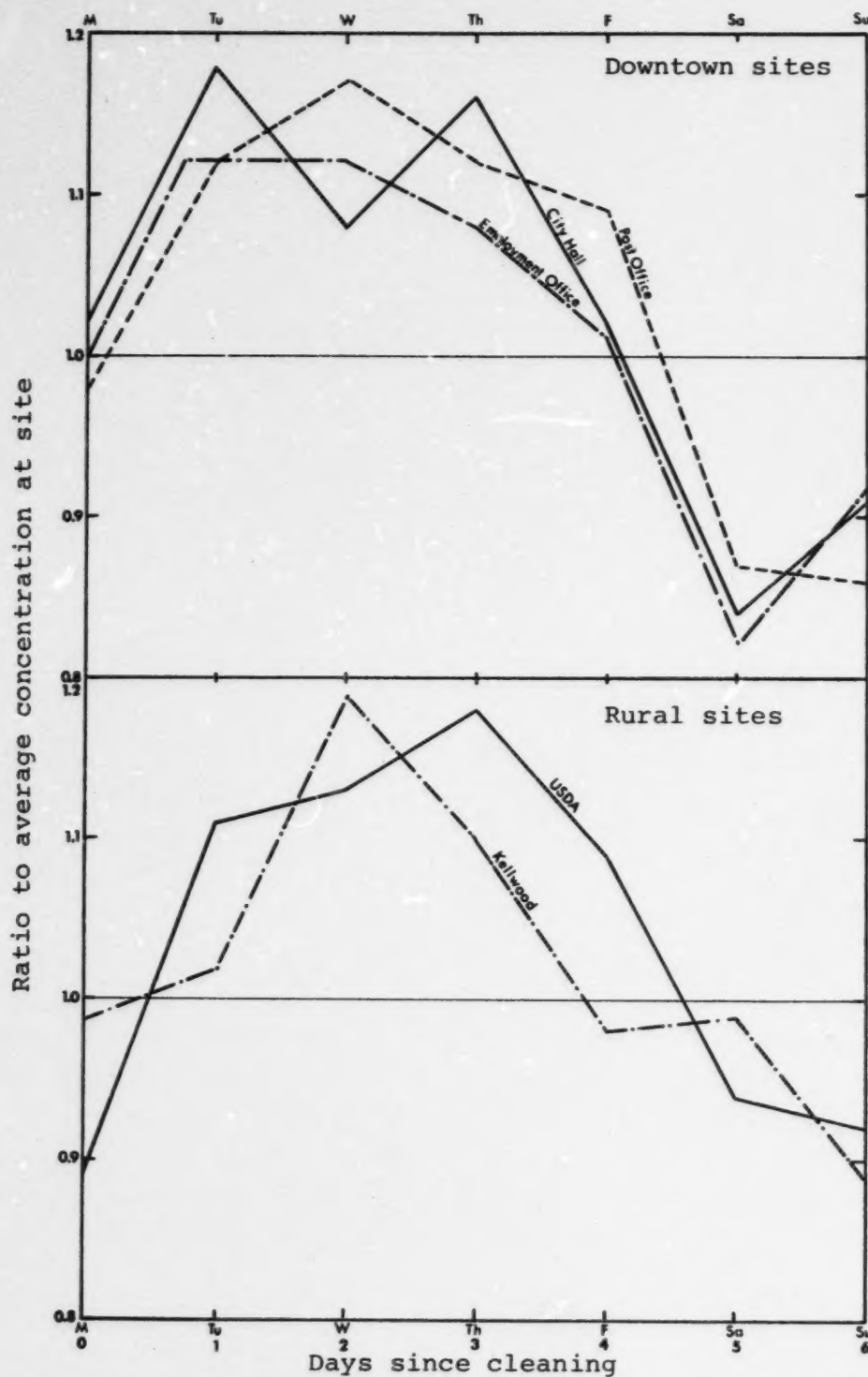


Figure 3-3. Average particulate concentrations by day of week in Twin Falls, Idaho.

the two rural sites was essentially the same as at the downtown sites, although the weekend effect was less pronounced.

The shape of the curve for the downtown sites matches the curves of days since flushing obtained in the Cincinnati street cleaning study, but the curves for the rural sites indicate that regional concentrations are low on Mondays even if there is no street cleaning nearby. Therefore, one of three conclusions can be drawn: the street cleaning was not affecting particulate concentrations significantly; it was affecting all sites near Twin Falls uniformly; or some other factor was influencing weekly variation at the rural sites in a manner similar to the street cleaning.

The GCA report on the Twin Falls particulate study concluded that street cleaning was an ineffective control measure for reducing street dust in Twin Falls.

Seattle, Washington

Control Program - A 1972 study of Seattle's Duwamish Valley, done by the Puget Sound Air Pollution Control Agency, indicated that 5 to 18 ug/m³ were added to particulate concentrations by mud carryout from unpaved roads and parking lots onto paved roads and its subsequent reentrainment.² The report recommended that mud carryout be reduced by paving or oiling of roads and parking areas as the most cost-effective control measure in this highly industrialized area.

As a result of these recommendations, the city initiated a \$2 million per year three-year program in 1974 to strip pave or seal coat roads and traffic areas in all parts of Seattle. A portion of this money was used on unpaved roads in the Duwamish Valley. Streets which would have required heavier paving because of truck traffic have been oiled to reduce dust and mud carryout. Approximately \$40,000 has been spent for oiling in the Duwamish Valley. By the end of 1976, the initial program for control of mud carryout in the Duwamish Valley was completed.

Analysis of Air Quality Data - The change in particulate concentrations in the Duwamish Valley relative to the rest of the Seattle (King County) area over the time period in which the mud carryout control program was implemented should provide a rough assessment of the effectiveness of the program. Point source emission reductions in the Duwamish Valley were nearly complete by the end of 1973. There were seven high volume sampler sites located in the Duwamish Valley during the period 1973 to 1976 and eleven sites in other parts of King County, including one rural location designated as a background site. Monthly average concentrations for the four year period are plotted in Figure 3-4.

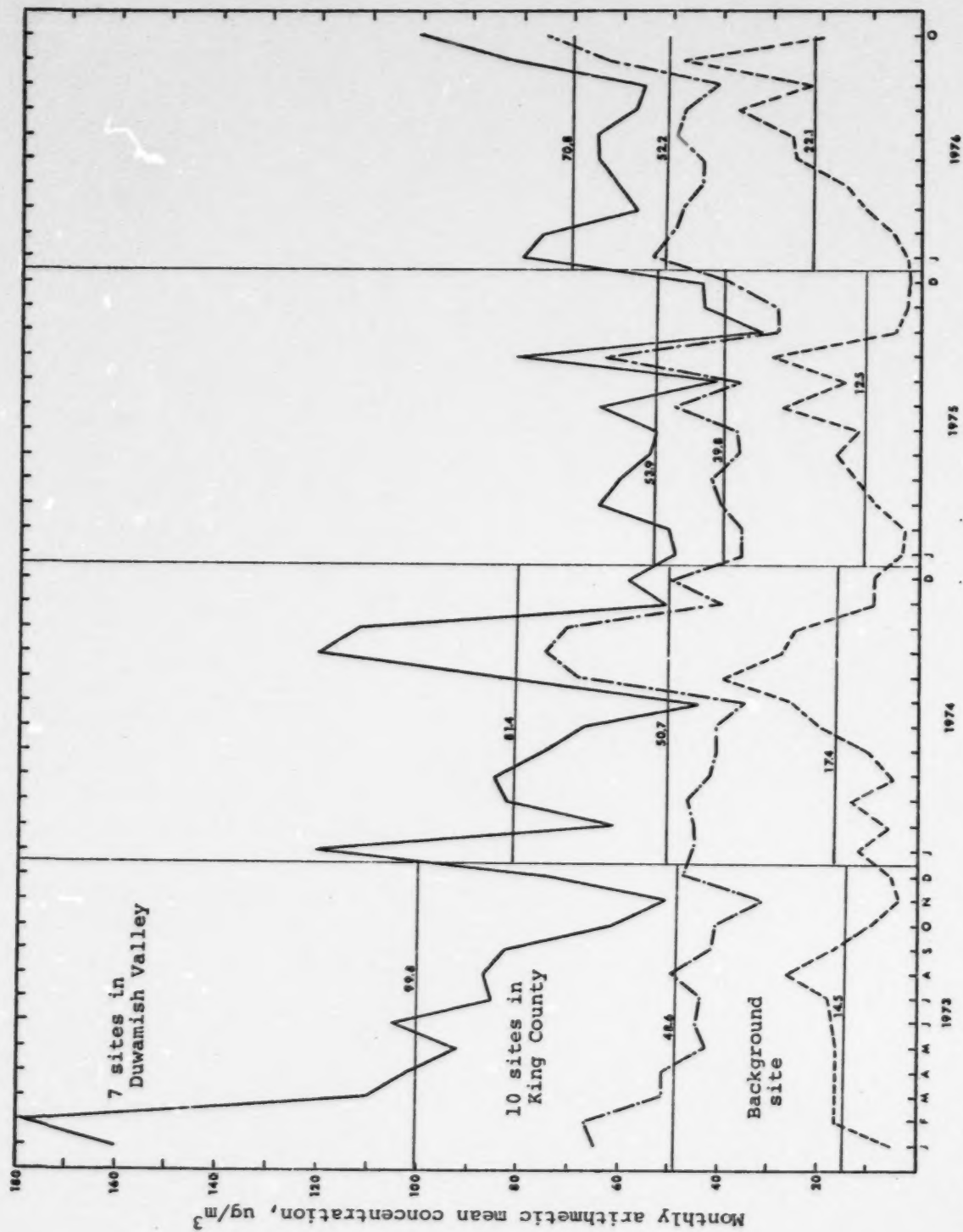


Figure 3-4. Change in particulate concentrations in the Seattle area.

Results and Conclusions - The paving program in the Duwamish Valley appears to have reduced ambient concentrations in this area relative to the rest of the metropolitan area. Most of the change in year-to-year averages at the other sites in King County can be attributed to changes in background concentration (see annual averages in Figure 3-4). In relation to either background concentrations or ambient concentrations in the rest of King County, there has been an improvement in the air quality of Duwamish Valley in the range of 12 to 22 ug/m³ (arithmetic) since 1974, the first year of the program. This is greater than the total impact from traffic-related emissions originally estimated by the Puget Sound agency but agrees quite well with a later estimate made in 1974 that motor vehicles and reentrained dust constituted about 39 percent of the ambient particulate in the Duwamish Valley (or about 32 ug/m³).¹² The improvement due to reduced reentrainment cannot be isolated from that of reduced unpaved road emissions. Both are thought to be significant.

UNTESTED MEASURES

Several potential measures were not evaluated in field tests. Two of these--reductions in vehicle-miles traveled (VMT) and modification of street sanding procedures--are thought to have enough potential to warrant some estimate of their effectiveness.

Reductions in VMT

According to data presented in Chapter 1 and Appendix A, ambient concentrations are directly related to traffic volumes on the nearest street and/or to traffic densities in the surrounding area. Therefore, reductions in these traffic volumes should result in proportional reductions in concentrations caused by reentrained dust. For example, a 20 percent reduction in VMT in an area where 45 ug/m^3 is contributed by traffic-related emissions should reduce average concentrations by 9 ug/m^3 .

Rerouting traffic to streets that are only a few blocks distant from its present path would probably just shift the location of the highest particulate concentrations slightly. The transportation controls with the most potential for achieving VMT reductions in a limited area with excessive particulate concentrations are well-marked alternative routes (several blocks away) which tend to disperse traffic densities in the urban area and direct traffic restrictions such as limited access zones or designated carpool lanes.

Modification of Street Sanding Procedures

In cities where sanding is used on streets for snow and ice control, modifications can be made in the sanding operations to reduce air quality impact without increasing the hazard of vehicle accidents. Some of these modifications are:

- replace the sand with salt or a salt/sand mix;
- plow streets instead of sanding;
- clean the sanding material from streets as soon as possible after each storm;
- apply material only at intersections and on hills and curves (reduce the amount applied);
- use sand that has been washed and sized.

It is not possible to quantify the air quality impact of each of these changes or their combinations.

In many cities which sand streets, seasonal particulate concentrations are significantly higher during the first quarter, or winter months. In Denver, particulate concentrations are at least 25 ug/m^3 higher during the first quarter than in the remaining three quarters.¹⁹ Much of this increase during the winter is attributed to street sanding. High 24-hour concentrations (in violation of the primary standard) in Montana cities were attributed largely to winter sanding operations.²⁰ In contrast, a study in Detroit, where streets are salted instead of sanded, showed that suspended particulate in the winter averaged 6.1 percent salt (sodium chloride) compared to a summer background of 0.55 percent salt.²¹ Therefore, salting of streets apparently increased average winter concentrations about 5 ug/m^3 . In the Kansas City and Cincinnati street cleaning studies, the effect of salting could not be identified on days after snowfalls even though salt residue was visible on streets in the study areas. Replacement of sand with salt is therefore estimated to reduce the effect of this reentrained dust source by more than 50 percent.

ADVERSE ENVIRONMENTAL EFFECTS FROM CONTROL MEASURES

Recently, numerous studies have called attention to a relationship between dirt loadings and storm water pollution. This is a cause of concern to public officials who have seen large investments in water treatment plants and collection systems partially nullified by this type of pollution. Sartor and Boyd found that runoff from street surfaces is generally highly contaminated and contributes considerably more pollutorial load than sanitary sewage during the same period of time.¹⁷ Shaheen concurred that storm water runoff is frequently a significant portion of the total annual water pollution.²² Thus, any reduction in material on street surfaces has the dual advantage of improving air quality and water quality.

Some of the control measures cited previously can serve this dual purpose. For example, wherever a measure controls soil erosion or trackout, the amount of material deposition on streets is decreased and the impact of subsequent reentrainment is thereby reduced. Concurrently, the decrease of material on streets reduces contamination of the urban water runoff.

However, in some instances, measures that improve air quality can have a detrimental effect on water quality. Flushing, which was shown to reduce particulate concentrations, does not remove material from streets but moves it from traffic lanes to the curb area. In subsequent rains, the suspended solids loadings in storm water runoff would not be reduced at all by the streets having been flushed. In fact, short-term concentrations might be increased because the material was already concentrated in the gutters.

A combination of flushing followed by a pickup of material in the gutter, with either broom sweepers or vacuums, would theoretically provide optimum cleaning for both air and water pollution control. However, in the two studies

reported in this chapter where a combination of flushing and sweeping was performed (Kansas City, Kansas and Twin Falls), no significant particulate concentration reductions were observed.

Based on limited available data, it appears that salting presents less of an air pollution problem than sanding. However, sanding (with clean sand) may be better from a water quality standpoint because of reduced chlorides in storm water runoff. In addition, the use of salt will accelerate corrosion of vehicles, reduce the life of highway structures, and cause damage to vegetation along areas adjacent to the streets.²³ Each of these adverse environmental effects of salting must be balanced against the air quality effects of sanding. Reducing the amount of either antiskid material used is desirable from an environmental standpoint. Use cannot be reduced to the point where accidents might increase, but monitoring for overuse and maintaining safe driving levels offers one feasible approach to reducing reentrained dust emissions and suspended solids or chlorides in runoff.

SUMMARY OF CONTROL MEASURE EVALUATIONS

Results of all the field studies and control measure evaluations are summarized in Table 3-6. None of the conventional street cleaning methods were found to be effective in every study in which they were investigated. Because of the mixed results, definite conclusions cannot be drawn relative to the effectiveness of street cleaning as a control measure for reentrained dust.

The relationship between cleaning and subsequent emission rates appears to be complex; emission rates are not directly related to the percent of street surface loadings removed from the traffic lanes (just as emission rates were not found to be closely related to the street surface loadings). Also, the street cleaning studies with streetside samplers tended to show a positive effect from cleaning operations, while those using regional network samplers in general failed to show an impact from street cleaning.

Flushing apparently reduced particulate concentrations significantly in two of the studies, showed no effect in two studies, and did not reduce monthly average concentrations but did reduce concentrations on the days with flushing in a fifth study. Some of the data indicated that flushing has an effect very similar to rainfall, with a substantial reduction in particulate concentrations on the day of flushing but little or no residual effect on following days. Weekly flushing in the two studies where no effect was noted may not have been often enough to produce a detectable reduction in concentrations. A reduction of 16 ug/m^3 on the days of flushing is recommended for estimating the impact of this street cleaning method in high traffic density areas.

Broom sweeping reduced average concentrations in one study but appeared to be ineffective in two others. This cleaning method has two operational limitations that make its use alone in reducing reentrained dust of doubtful

Table 3-6. SUMMARY OF CONTROL MEASURE EVALUATIONS

Study	Control measure	Effectiveness	Comments
Kansas City, Missouri	flushing broom sweeping	8-18 ug/m ³ aver negligible	
Cincinnati	flushing	negligible	conc. on days of flushing 16 ug/m ³ lower
	broom sweeping vacuum sweeping	6-20 ug/m ³ aver negligible	
Westwood	vacuum sweeping	negligible	compared to broom sweeper
Construction site	manual cleaning (intermittent)	5-10 ug/m ³	in area around access streets
	manual cleaning (continuous)	10-20 ug/m ³	in area around access streets
	municipal cleaning	negligible	
New York-New Jersey	flushing	16 ug/m ³ on day of flushing	
Kansas City, Kansas	flushing added to existing broom sweeping	negligible	on subregional scale
Charlotte	regenerative air cleaning	negligible	on subregional scale
Chicago	daily broom sweeping	negligible com- pared to every other day cleaning	
Twin Falls	flushing and broom sweeping	negligible	
Seattle	reduction of mud carryout by paving	15-35 ug/m ³	part of impact due to reduced emissions from unpaved roads, etc.

value--it moves material from the gutter back into the street for pickup and it is not efficient in removing fine particles. There were some indications that the optimum frequency for broom sweeping from an air quality standpoint might be every two or three days rather than daily. The application of this cleaning method in the Cincinnati study was probably near its optimum--6 to 20 ug/m³ reduction in average concentrations. It is not possible from available data to estimate the air quality improvement that could normally be expected.

None of the three studies which evaluated the air quality impacts of vacuum or regenerative air sweepers showed reductions in concentrations associated with their use. In the Cincinnati study, street loading measurements showed that vacuum sweeping removed a higher percentage of material from the streets than broom sweeping, but the vacuum sweepers always collected less total weight of material in their hopper over the 13 curb-miles than the broom sweepers. Dust was often observed escaping from the top of the vacuum sweeper while it was operating. In the Westwood study, there was apparently not enough contribution from reentrained dust to ambient concentrations so that the improved street cleaning was detectable in reduced concentrations.

Both of the mud carryout control studies showed significant reductions in particulate concentrations. At the construction site study, the impact from mud carryout was reduced by 30 percent by intensive manual cleaning near the access point. Even though control of such sources has an effect only within the area of impact of the construction site, about a 1000 ft radius around the site, that effect is in the area where locally high concentrations occur.

Data from Seattle indicate that reductions similar to those obtained at the construction site study can be achieved

over a subregional area through a comprehensive mud carryout control program for smaller sources such as unpaved parking lots, roads, and shoulders. Annual average concentrations were reduced 12 to 22 ug/m³ over a 16 mi² industrial area by required strip paving or oiling to eliminate trackout.

Although no field studies were conducted to evaluate traffic volume reductions or modified street sanding procedures, some data are available which indirectly show that both of these potential control measures can be effective if they are applicable in a particular area. The air quality improvement that can be obtained by modifying street sanding procedures is, of course, highly dependent on the climate and existing street sanding practices in the area.

Because of the large number of measures being evaluated and the conflicting results on street cleaning as a control measure, the data presented in this chapter provide only a preliminary assessment of these measures rather than a conclusive examination. There are still questions to be answered with pilot studies before regional reentrained dust control programs can be implemented.

4. COST DATA

Cost data were compiled for all the control measures except reduction in traffic volumes. Costs for street cleaning activities were compiled separately for operating and capital costs. The primary source of operating and maintenance cost data was the American Public Works Association (APWA) 1975 Survey of Street Cleaning Practices (unpublished).²⁴ Other operating data for specific cities were compiled from the literature and by contact with public works officials. Capital equipment costs for selected equipment were obtained directly from vendors.

Costs relevant to enforcement or inspection activities are not included.

STREET CLEANING COSTS

Capital Costs

Capital costs of street cleaning equipment are summarized in Table 4-1. For the major manufacturers represented, the cost of municipal sized vacuum units ranges from \$43,000 (7 yd³ model) to \$56,000 (16 yd³ model). A smaller model (3 yd³) for shopping centers and similar uses sells for about \$12,500. Broom sweepers range in cost from approximately \$20,000 (3-4 yd³ models) to \$45,000 (5 yd³ models). The regenerative air units cost an average of \$30,000 (3.5-6 yd³ models). Generally, vacuum sweepers are larger in capacity than broom sweepers and cost approximately 24 to 72 percent more. However, their cost per cubic yard capacity is less than that of broom sweepers. Note that these cost data are

Table 4-1. SUMMARY OF CAPITAL COSTS FOR
SELECTED STREET CLEANING EQUIPMENT

Manufacturer/ Model	Type equipment	Sweep speed, cfm	Sweep path, in.	Capacity, lb & yd ³	Cost, 1976 \$	Cost, \$/yd ³ cpy
Ecototec VACU-Sweep	Vacuum with 1 gutter & 1 wide sweep broom	6,000	84	13,000 7	Base-43,000 Dual-49,000	6,143 7,000
Elgin Whirlwind	Vacuum with 1 gutter & 1 wide sweep broom	10,000	93	10,000 7.4	45,000 to 55,000	6,081 to 7,432
Central Engr Vac-all (E-5-16)	Vacuum w/optional gutter broom	12,000	57 ^a	68,000 16	56,000	3,500
Central Engr Vac-all (E-5-13)	Same	12,000	57 ^a	13	53,000	4,077
Central Engr Vac-all (E-10)		12,000	57 ^a	50,000 10	50,000	5,000
Schwarze Indus Products, Inc. Supervac	Vacuum-mounted on 3/4 or 1 ton truck, gutter broom optional			3,000 3	12,500	4,167
Tymco, Inc. Model 600	Regenerative air with 1 gutter broom		108	6	32,000	5,333
Tymco, Inc. Model 350	Regenerative air with 1 gutter broom		108	3.5	28,000	8,000
Eintyre	Flusher			n.a.	27,300	n.a.
Elgin Pelican	Broom sweeper with 3 wheels, 1 or 2 gutter brooms, 1 wide sweep broom		96 to 120	9,000 3	25,000 to 38,000	8,333 to 12,667
Elgin White Wing ^b	Broom sweeper with 3 wheels, 1 gutter broom, 1 wide sweep broom		96 to 120	9,000 4	20,000 to 28,000	5,000 to 7,000
Tennant Co. 92 Power Sweeper	Broom sweeper with 3 wheels, 1 gutter broom, 1 wide sweep broom		66	1,800 3	15,000	5,000
Athey Products TE-4	Broom sweeper with 4 wheels, 1 or 2 gutter and 1 wide sweep broom		90 to 120	4	35,000	8,750
Athey Products TE-3	Broom sweeper with 4 wheels, 1 or 2 gutter and 1 wide sweep broom		90 to 120	3	34,000	11,333
FMC Corp. Wayne Model 12	Broom sweeper with 4 wheels, 4 gutter and 1 wide sweep brooms		120	12,000 5	45,000	9,000
FMC Corp. Wayne Model 984	Broom sweeper with 3 wheels, 2 gutter and 1 wide sweep brooms		96	4	42,500	10,625
FMC Corp. Wayne Model 973	Same		96	3	40,000	13,333

^a estimated

^b Pelican model, without lifting hopper

manufacturers' quoted prices for normally-equipped machines and could vary considerably with the addition of optional equipment. Also, prices requested by potential purchasers through competitive bidding may be different than these quotes.

Operating Costs

Annual operating costs for street cleaning summarized from the 1975 APWA study are presented in Table 4-2. For the items tabulated, reported costs were aggregated for all equipment types in use by the survey respondents.

The costs for specific aspects of street cleaning programs, such as sign posting or water for flushing, were expected to vary over a wide range because they are total budget costs for all sizes of cities. However, the cost data normalized for such parameters as tons of material collected, curb-miles cleaned, or population served should be much more consistent. The enormous range of reported costs per curb-mile cleaned has led to the conclusion that several survey respondents misinterpreted the questionnaire and reported total annual operating costs per curb-mile of streets in their jurisdiction rather than the cost to clean one curb-mile. Such errors would bias the median value upward slightly and make the calculated mean value meaningless.

Table 4-3 presents the same operating cost data disaggregated by city size. The same problem with reported costs per curb-mile arises here, and the data indicate that the misinterpretations were made by respondents from the smaller cities. The costs per cubic yard of material collected and per person do not reveal any definite relationship between costs and city size.

The APWA operating cost data are tabulated by climate zone in Table 4-4. With the exception of zone 2, the Southwestern states, street cleaning costs per cubic yard

Table 4-2. SUMMARY OF ANNUAL OPERATING COSTS FOR STREET CLEANING

Operating costs	% possible data represented	Mean	Median	Standard deviation	Data range 10 percentiles 90
\$/ton	33	20.79	12.20	20.35	2.25 53.57
\$/yd ³	58	17.55	13.24	15.40	3.37 38.00
\$/curb-mile	69	86.61	7.00	165.85	2.96 300.00
\$/person	81	1.33	1.18	0.78	0.52 2.51
<u>Specific</u>					
Sign posting	18	5,335	540	17,202	0 9,750
Street cleaning ^a	73	197,718	58,520	664,232	15,000 283,735
Transport	33	23,735	5,864	51,183	1,200 51,000
Dump fee	28	8,841	142	32,960	0 11,339
Water cost (flushers)	32	6,376	300	27,748	0 3,990
Total		206,980	69,800	675,815	17,300 328,221

^a Generally includes these items: equipment operation and maintenance, labor, fuel, depreciation, other related costs.

Source: APWA 1975 Survey of Street Cleaning Practices.

Table 4-3. OPERATING COSTS BY CITY SIZE

Cost parameter	Population class, x 10 ³						
	0-10	10-25	25-50	50-100	100-250	250-500	>500
\$ / yd ³							
mean	7.43	16.58	19.57	17.50	14.94	28.22	11.70
count	2	36	28	14	4	2	2
s.d.	7.68	14.82	17.34	16.90	10.92	1.41	2.40
\$ / curb-mi							
mean	61.50	103.07	99.84	66.87	7.08	9.02	5.80
count	2	43	34	16	5	3	2
s.d.	82.73	175.09	192.92	129.05	4.30	5.43	1.70
\$ / person							
mean	1.32	1.21	1.45	1.31	1.74	1.51	1.62
count	2	57	35	18	5	3	3
s.d.	0.91	0.78	0.71	0.74	1.11	0.87	0.97

Table 4-4. OPERATING COSTS BY CLIMATE ZONE

Cost parameter	Climate zone				
	1 California dry summer, mild wet winter	2 Southwest arid, hot	3 Southeast hot wet sum- mer, mild winter	4 Midcontinent hot summer, short winter	5 Northern warm sum- mer, long winter
\$ / yd ³					
mean	19.06	7.38	17.79	19.52	16.94
count	22	7	17	23	19
s.d.	16.33	5.28	13.58	17.54	15.40
\$ / curb-mi					
mean	63.92	5.23	36.85	195.14	97.15
count	33	7	22	20	23
s.d.	136.60	4.45	103.18	238.44	165.63
\$ / person					
mean	1.47	0.64	1.59	1.11	1.37
count	33	7	25	32	26
s.d.	0.73	0.38	0.86	0.77	0.67

Source: APWA 1975 Survey of Street Cleaning Practices.

collected or per person do not appear to be closely related to climate. Variations in cost within each climate zone, as measured by the standard deviation, are much greater than the variations in mean values for different zones. It is surprising that street cleaning costs are not climate dependent. Apparently, the extra costs of spring cleanups in northern climates are offset by shorter cleaning seasons.

Table 4-5 presents operating costs for specific types of street cleaning equipment. These data were obtained by direct contact with street department officials and from the literature. Equipment-related costs were most often reported on the basis of hours of equipment use. To derive costs on a \$/curb-mile basis where this information was not reported directly, it was assumed that all types of equipment cleaned about 20 curb-miles per eight hour shift. Labor rates vary somewhat in different parts of the country but not to the extent of the variance in equipment-related costs. In order to permit greater ease of comparison of total operating costs for the three equipment types, the data are summarized below:

City	Total operating cost, \$/curb-mi ^a		
	Vacuums & R. air sweepers	Broom sweepers	Flushers
Cincinnati	8.94	8.24	4.03
Kansas City	-	13.57	-
Charlotte	4.06	-	3.51
Milwaukee	-	9.41	-
Memphis	8.20	10.00	-
Beaumont	4.50	8.75	-
Love's Park	3.75	5.75	-
Sparks	1.56	1.94	-
Average	5.17	8.24	3.77

^a 1976 \$

Tab 4-5. OPERATING COSTS FOR SELECTED CITIES

City/equipment type	Equipment		Operator		Total ^a	
	\$/hr	\$/curb-mi	\$/hr	\$/curb-mi	\$/hr	\$/curb-mi
Cincinnati, OH						
Vacuums	16.00	6.40 ^b	6.34	2.54 ^b	22.34	8.94 ^b
Broom sweepers	14.40	5.76 ^b	6.23	2.49 ^b	20.63	8.25 ^b
Flushers	3.85	1.56 ^c	6.23	2.49 ^b	10.08	4.03 ^b
Kansas City, MO						
Broom sweepers	-	11.34	-	2.23	-	13.57
Charlotte, NC						
Regen. air	-	2.06	5.00 ^c	2.00 ^b	-	4.06
Flushers	-	1.51	5.00 ^c	2.00 ^b	-	3.51
Beaumont, TX						
Vacuums	-	-	-	-	11.26	4.50 ^b
Broom sweepers	-	-	-	-	21.87	8.75 ^b
Love's Park, IL						
Vacuums	-	-	-	-	7.88	3.75
Broom sweepers	-	-	-	-	12.08	5.75
Sparks, NV						
Vacuums	0.64	0.13	5.00	1.38	5.64	1.56
Broom sweepers	1.98	0.55	5.00	1.38	6.98	1.94
Milwaukee, WI						
Broom sweepers	-	-	-	-	23.48	9.41
Memphis, TN						
Vacuums	15.09	6.16	5.00 ^c	2.04	20.09	8.20
Broom sweepers	13.40	7.28	5.00 ^c	2.72	18.40	10.00

^a All costs in 1976 dollars

^b Assumes an average cleaning rate of 2.5 curb-mi/hr
(8 hr shift)

^c Assumed labor rate

Several conclusions that may be drawn are:

- ° broom sweepers are generally more expensive to operate on a curb-mile basis than vacuums or flushers;
- ° flushers incur the lowest operating costs, probably due to less required maintenance;
- ° there are no major differences in street cleaning costs based on either city size or geographic location;
- ° differences in accounting systems and methods of cost reporting exist among jurisdictions; these could explain some of the variation in cost between cities (for example, the most commonly accounted for cost items are equipment operation, maintenance, parts, downtime, fuel and labor, but capital depreciation may or may not be included);
- ° the average broom sweeping cost per curb-mile determined by contacts with a few public works departments, \$8.24, agrees well with the median cost of \$7.00 reported in the 1975 APWA survey.

MODIFIED SNOW CONTROL COSTS

Basic cost data for snow control procedures such as sanding, salting, plowing, and cleanup are presented in this section to permit estimation of the extra costs of modifying a city's snow control program. Information specific to the city is also needed before the total costs of any program modification can be calculated: miles of road to be deiced, number of snowstorms per year, and current practices.

Some comprehensive cost-benefit analyses have been performed to determine whether salt or sand is better antiskid material for use on public roads.^{23,25,26} These analyses considered antiskid material, application, corrosion, water pollution, and vegetation damage as cost items and traffic safety, public health, time savings, and reduced fuel use as benefits. Air quality was not considered. Results of these studies have varied widely, depending on the input data used

and assumptions made. Therefore, only the material and application costs (which are minor compared to the indirect costs and benefits cited) are presented herein.

Costs per ton for salt and sand are:²⁷⁻³²

	<u>Average</u>	<u>Range</u>
Salt	\$17	\$9-28
Sand	5	2-9

Application costs, which include equipment, labor, gasoline, supervision, and garage support, are the same per ton of salt or sand applied--about \$3.00.^{28,33} However, since sand must be applied at higher rates than salt per mile of road, it costs more per mile to apply. For example, with average application rates of 500 lb/mi²⁷ and 800 lb/mi for salt and sand, respectively, the cost per mile would be \$0.75 and \$1.20.

The limited data on plowing indicate that plowing a mile of road costs approximately \$24.²⁹ If snow removal by truck is required, the additional costs are about \$315 per mile cleared.²⁹

The costs for removing antiskid material on a regular basis (after each application) would be the same as for regular street cleaning. Therefore, data from the preceding section can be used. Spring cleanup has been included as a major cost item in several published articles on snow and ice control. In cases where salt and sand are compared, it is the concensus that cleanup is twice as expensive when sand is used as when salt alone is used.^{30,34}

The application of less material as a control measure for reentrained dust would obviously have a negative cost and show to be the most cost-effective measure.

MUD CARRYOUT CONTROL COSTS

Construction activity control measures for which cost data were available include wheel washing at the site, manual or machine street cleaning of the access street by the contractor/city/private firm, truck covering, and covering traffic routes on site with gravel. Costs were also estimated for the paving and oiling of unpaved parking lots. These data are summarized in Table 4-6.

Most large construction sites would probably require implementation of more than one control measure. It is estimated that one construction worker stationed near the entrance could keep the area cleaned continuously with half his available time, with the remainder for traffic control and other assignments. One private street cleaning firm estimates a labor savings to the contractor of \$15-20 per hour if they perform the cleanup job.³⁵ They use flushers exclusively and charge \$26 per hour per truck with a \$39 minimum charge. In Chicago, where mud carryout regulations for construction activities are rigidly enforced, the cleaning costs to the contractor are written into the total job budget as a matter of routine and are not easily identified.

Truck covering is regarded as an ancillary control technique and is probably the least costly of all the available alternatives. It should, however, be considered in combination with one or more of the above measures. Covering traffic areas on the construction site with coarse gravel may be a cost-effective measure depending on the size of the areas.

Paving, oiling, and seal coating costs for parking lots and other exposed areas have been estimated to cost from \$0.07-0.50 per ft² of area covered or paved.

Table 4-6. COSTS OF MUD CARRYOUT CONTROL MEASURES

Control measure	Capital		Operating	
	Cost, 1976 \$	Cost basis	Cost, 1976 \$	Cost basis
<u>For construction sites</u>				
Wheel washers	5,000-7,500	equipment type plus installation	\$3/truck	lost time
Manual cleaning	-	-	\$5-12/hr ^a	labor
Machine cleaning	12,500-56,000 ^b	cleaning machine type	\$6-22/hr ^e	labor/equipment
Truck covering	0.04-0.60/ft ²	tarpaulin; \$/ft ² truck-bed	\$3/load	lost time
Cover w/ gravel	0.12/ft ²	area size	-	-
<u>For other carryout sources</u>				
Parking lot paving	0.20-0.50/ft ^{2c}	lot size	-	-
Oil/Seal coat	0.07-0.13/ft ^{2d}	lot/area size	-	-

^a Total cost to contractor; range of 10 small/large cities (median = \$7.68; mean = \$8.37).

^b Table 4-1.

^c Cost varies with weight bearing capacity of paving laid.

^d Oil = least cost.

^e Table 4-5.

COST-EFFECTIVENESS OF INDIVIDUAL MEASURES

Using the summarized data on control measure effectiveness from Table 3-6, preliminary estimates of cost-effectiveness for promising measures have been made to provide some guidance in selection of measures. Control measures which failed to demonstrate a significant reduction in particulate concentrations have not been considered since their calculated cost-effectiveness would be infinite. The five measures reviewed were flushing, combined flushing/sweeping, modification of street sanding procedures, control of mud carryout from construction sites, and control of mud carryout in a large industrial area.

Cost estimates have been developed for hypothetical urban areas exceeding the annual particulate air quality standards.

Flushing

The hypothetical area in which the annual particulate air quality standards are being exceeded is three mi by five mi in size, with approximately 100 mi of arterial streets (200 curb-mi). The cost of flushing these streets once would be \$754, based on an average flushing cost of \$3.77 per curb-mi. Flushing three days per week, eight months per year would cost \$78,400 and is estimated to lower concentrations in the non-attainment area by 16 ug/m^3 on the day of flushing, based on data from the Cincinnati and New York-New Jersey field studies. This would reduce the annual average concentration by $(16) \left(\frac{3}{7}\right) \left(\frac{8}{12}\right) = 4.6 \text{ ug/m}^3$. Similarly, flushing five days per week for eight months per year would cost \$130,700 and is estimated to reduce particulate concentrations by 7.6 ug/m^3 .

Combined Flushing/Sweeping

For the same non-attainment area, the cost per curb-mi of flushing followed by sweeping would be the sum of the individual costs for the two cleaning operations, or about \$12.01 per curb-mi. The cost for cleaning the 200 curb-mi once would be \$2402, and the cost of a scheduled three day per week cleaning program for eight months per year would be \$249,800.

No direct information was obtained in the field studies on the air quality improvement associated with combined flushing/sweeping. The Kansas City, Kansas data showed no additional impact when flushing was combined with an existing sweeping program. Twin Falls, Idaho data indicated that weekly flushing/sweeping probably did not have a significant effect on air quality in that city, although concentrations were consistently lower on the days when the cleaning was done. It has been assumed for the cost-effectiveness analysis that flushing/sweeping would have the same effect on air quality as flushing alone. This assumption precludes combined cleaning from being as cost-effective as simply flushing. One of the primary benefits of picking up the material that is flushed to the gutter--that removal would reduce storm water loadings on the sewage treatment system--does not enter this cost-effectiveness analysis because effectiveness is measured only in terms of air quality improvement.

Modification of Street Sanding Procedures

For the same non-attainment area, the direct costs of modifying street sanding procedures by switching to salt and cleaning as soon as possible after every application are estimated from the extra cost of salt compared to sand and the cost of the additional street cleaning. The costs do not include the savings that should be realized by lower spring cleanup costs if the streets are cleaned periodically

during the winter and salt is used in place of sand, nor do they include possible indirect costs associated with salting such as decreased vehicle lives. Assuming a need for sand or salt on 10 occasions per year, the amount of sand applied on the arterials would be 400 tons per year (at an application rate of 800 lb/mi). This would cost \$3200 if sand costs \$5.00 per ton and can be applied for an additional \$3.00 per ton. Substitution of salt for all 10 applications at a rate of 500 lb/mi²⁵ and an average cost of \$20 per ton (including application at \$3.00 per ton) would total \$5000 or \$1800 more than the sand.

Removal of salt residue and other material after each application is estimated to cost \$8.24 per curb-mi (average broom sweeper costs), or a total of \$16,500. Thus, the additional cost of both modifications of the snow control program would be \$18,300.

The improvement in air quality is approximated at 5 ug/m³ for the winter quarter (at least a 50 percent reduction in contribution and a residual impact with salting of 5 ug/m³), or a 1.2 ug/m³ reduction in the annual arithmetic mean.

Control of Mud Carryout from Construction Sites

The most effective control measure at construction sites was found to be immediate manual cleaning. The cost of an employee on half-time assignment to clean the entrance area to the construction site would be (8 hr) (1/2) (\$8.37/hr) = \$33.50 per day. For a year of five-day weeks at a construction site, the total cost would be \$8400.

The improvement in air quality due to the cleaning would be 15 ug/m³ over an area of about 1000 ft radius (0.1 mi²). Since this is a very limited area of impact, control of mud carryout at construction sites cannot be compared directly with other measures. Per unit area, the cost of

construction site cleanup is more for each ug/m^3 reduction in particulate concentrations than the four measures with regional impact. However, construction site control has its effect entirely in an area with elevated concentrations.

Control of Mud Carryout from an Industrial Area

The control program for mud carryout sources in the Duwamish Valley (see pages 3-28 to 3-30) provides the cost-effectiveness data for this measure. An average reduction of $17 \text{ ug}/\text{m}^3$ over the 16 mi^2 area of the valley was achieved for a total capital cost of \$1-2 million (assume \$1.5 million). Costs for the other measures were annual costs rather than capital costs. With an interest rate of six percent (municipal) and a seven year assumed life for the strip paving, the equivalent annual cost for the air quality improvement is \$268,700.

The cost-effectiveness data for the five measures are summarized in Table 4-7. Comparison of the data for different measures indicates that modification of street sanding procedures is the most cost-effective, followed closely by control of mud carryout from an industrial area and street flushing. The costs per unit improvement in air quality for these three measures with potential impact over an entire subregional area fall within a relatively small range. Even the more expensive construction site control measure can be justified as the most feasible means of preventing concentrations above the ambient air quality standards in the immediate vicinity of a construction site. There is no information to indicate whether the combinations of these measures have an additive effect in reducing particulate concentrations.

Given the relative accuracy of the input data for the cost-effectiveness analysis, it should be concluded that

Table 4-7. COST-EFFECTIVENESS OF CONTROL MEASURES

Control measure	Annual cost, \$	Av reduction ₃ in conc, ug/m ³	\$ per ug/m ³ reduction	Area affected
Flushing	78,400	4.6	17,000	3x5 mi
	130,700	7.6	17,200	3x5 mi
Combined flushing/sweeping	249,800	4.6	54,300	3x5 mi
Modification of street sanding procedures	18,300	1.2	15,200	3x5 mi
Control of mud carryout from construction sites	8,400	15.0	560	0.1 mi ²
Control of mud-carryout from an industrial area	268,700	17.0	15,800	16 mi ²

costs may not provide a sufficient criterion for selection of a control strategy. The measure or measures that can be adapted most readily to existing public works practices would probably be preferable to the most cost-effective measure.

Without data for a direct comparison, it appears that all of these control measures for reentrained dust have substantially lower costs than point source controls that would have an equivalent impact on particulate air quality.

5. OPTIMIZING REENTRAINED DUST CONTROL MEASURES

It is evident that the field studies did not provide conclusive data on which recommendations for control actions could be based. However, some specific questions were answered by the field studies, and information from personal contacts with public works personnel and from the literature search revealed other methods of improving the efficiencies of the control measures. This chapter summarizes the information that has been assembled to date on optimizing reentrained dust control measures. There were no field studies for street sanding or traffic volume reduction measures, so the discussion is confined to improved street cleaning and mud carryout controls.

STREET CLEANING

Current Street Cleaning Practices

Many cities have an intensive four to six week spring cleaning to remove debris accumulated during the non-cleaning season and sand from the winter's snow and ice control programs. They may operate two 8-hour shifts daily to cover their entire street network. In some cities, any other cleaning that is done is undertaken only as needed. More commonly, a routine street cleaning program operates from April through October to cover the entire city on a systematic basis.

In 1975, the American Public Works Association (APWA) performed a survey of public works officials on various aspects of street cleaning practices.²⁴ From the 250 agencies

included, a total of 152 responses were received. This survey indicated that 42 percent of the cities clean their central business district (CBD) daily; 10 percent of the cities clean commercial areas daily and 40 percent clean weekly; and 25 percent of the cities clean residential areas weekly.

Most of these 152 agencies are presently using either 3-wheel or 4-wheel mechanical sweepers and almost half these agencies also have flushers. A previous APWA survey conducted in 1971 indicated that half the cities surveyed included flushing as part of their street cleaning (20 percent flushed before, 45 percent flushed after, and 35 percent flushed both before and after sweeping). Thirty-five agencies reported in the 1975 survey that they use vacuum sweepers and 14 agencies use regenerative air sweepers. Response to the questionnaire indicated further that fewer agencies in the future will have the mechanical sweepers and flushers but the number of agencies using vacuum sweepers was projected to remain about the same.

In response to questions relative to their public works budgets, most officials felt that street cleaning was gaining in importance in their overall public works programs. Responses to these questions are summarized below:

Time span	Response of agencies surveyed, %		
	Smaller budget	Same budget	Larger budget
Recent past (1970-75)	13	56	31
Near future (1976-80)	11	53	36
Distant future (after 1980)	10	43	47

It is interesting to note that the same officials who thought that street cleaning would increase as an item of budget also indicated a trend to fewer types of equipment in their cities.

Optimizing Street Cleaning

Even cities with frequent, systematic street cleaning have an air quality problem due to reentrained dust. Certain modifications of common practices offer a possible means for improving air quality. Six of these modifications are discussed below.

Equipment - Flushing showed the most promise for reducing reentrained dust. It wets the streets, causing dust suppression until the surface is completely dry, and moves material out of the traffic lanes to the gutters. The only limitation on the use of flushers is in areas where water availability is restricted. Flushers use 3,000 to 4,000 gallons of water per mile of street, or up to 70,000 gal/day. Therefore, street flushing could easily constitute 1 to 2 percent of a city's total water consumption.

Flushing can also be used in combination with subsequent material pickup by a broom, vacuum, or regenerative air sweeper. This combination method results in very effective removal because the material is wet and is concentrated in the gutter. However, data in Chapter 4 showed that flushing followed by sweeping is much more expensive than just flushing, with no demonstrated additional improvement in air quality.

Broom sweeping has two operational characteristics that make its use alone of doubtful value--it moves material from the gutter back into the street for pickup and it is not efficient in removing fine particles. It reduced particulate concentrations in only one of three field studies.

Neither vacuum sweepers nor regenerative air units produced reductions in particulate concentrations in field studies.

Frequency - Flushing is effective in reentrained dust control primarily on the day it occurs, with little residual effect, as shown in Figure 5-1. In that respect, it is similar to rainfall. Because daily flushing is as effective *per time* as infrequent flushing, from an air quality standpoint it should be done as frequently as possible. In areas where particulate concentrations are above the air quality standard, flushing could be done daily or every other day.

This frequency of cleaning is not recommended for broom or vacuum sweeping. Higher than average particulate concentrations were observed on days with sweeping, probably due to the cleaning operations breaking loose material adhering to the street surface, redistributing it, and temporarily making more material available for reentrainment. The curves of concentrations versus time since cleaning presented in Figure 5-2 show that the lowest concentration usually occurs on the first day after cleaning, with a continual increase thereafter. Assuming that broom or vacuum sweeping does have some positive effect on air quality by removing material from the street (even if this impact was not detectable in the field studies), it appears that sweeping should not be done more often than every two to three days.

Location - The direct relationship observed between particulate concentrations and traffic volume indicates that there are advantages to concentrating cleaning efforts on streets with high traffic volumes. The relationship between traffic and reentrained dust emissions suggests that frequent (daily or every other day) cleaning of major arterials and less frequent cleaning in the CBD and on residential streets

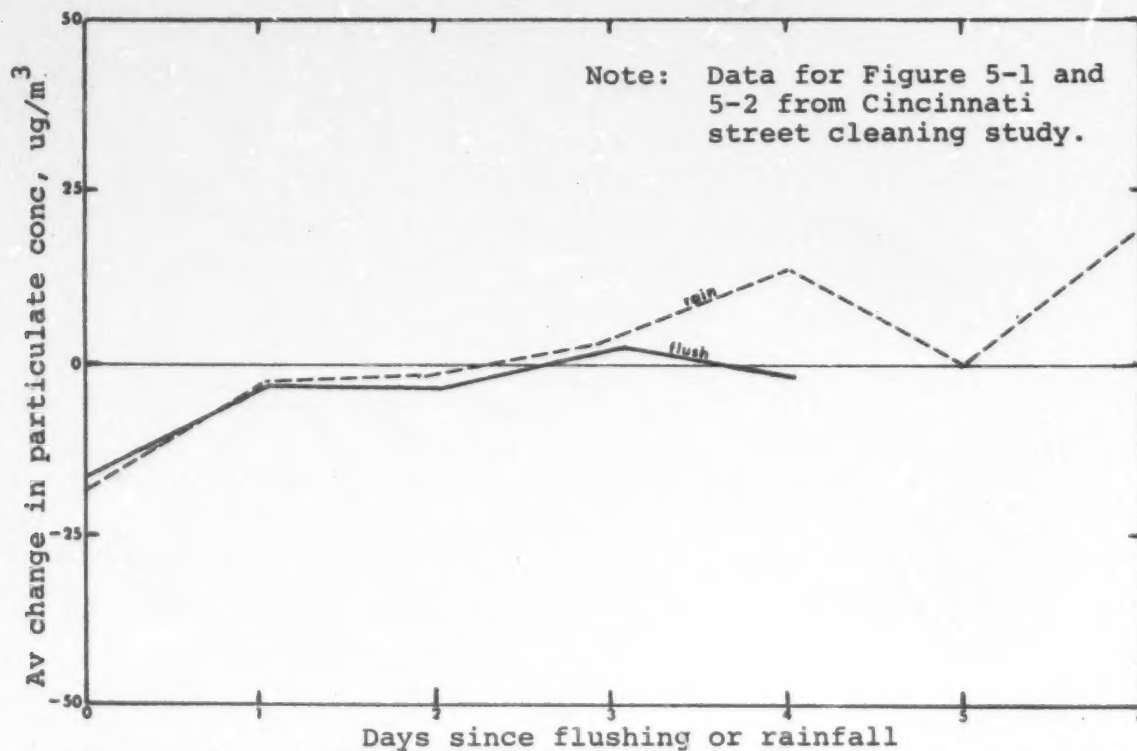


Figure 5-1. Effectiveness of flushing and rainfall in reducing particulate concentrations.

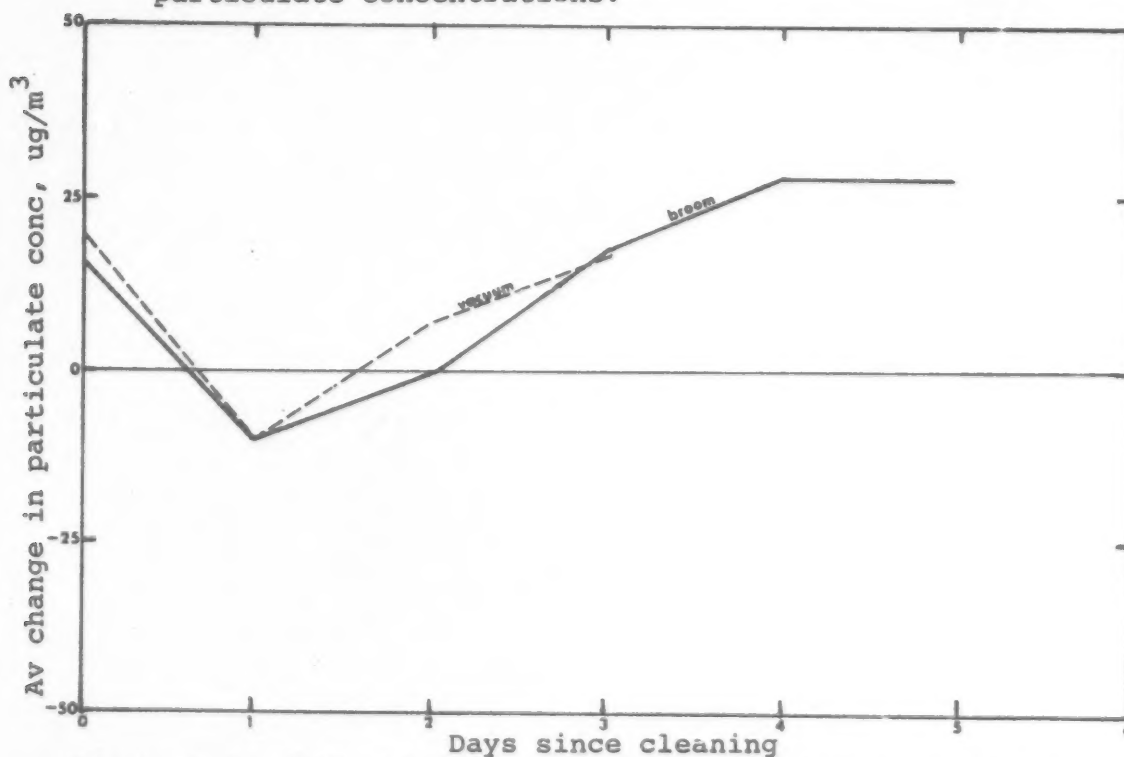


Figure 5-2. Effectiveness of street cleaning in reducing particulate concentrations.

might reduce total emissions. Many cities with comprehensive street cleaning programs observe the following schedule: daily cleaning in the CBD; weekly cleaning of major arterials and industrial areas; and every other week or monthly cleaning of residential areas. A reallocation of the cleaning effort to every other day in the CBD and on major arterials with remaining equipment operating as often as possible in industrial and residential areas appears to offer a potential for improving air quality.

Cleaning Season - The removal of excessive materials as they accumulate during the winter is preferable to an intensive spring cleanup. The length of time between cleaning, the application of antiskid material, and the greater amount of dirt that is deposited from vehicle undercarriages causes higher street loadings in winter. Use of flushers would not be practical, even during periods with temperatures above freezing, because temperatures would usually be low at night and could cause icing. However, sweeping the streets whenever weather permits throughout the winter season would be helpful in lessening the air quality impact from excessively dirty streets. A similar situation occurs in the fall when leaves should be removed from streets to reduce this potential source of dust and subsequent reentrainment.

Operator Training - One reference recommended increased training of equipment operators.¹⁷ This would be particularly important with respect to the air quality benefits of certain cleaning procedures. Training and performance are thought to be directly related, but only 43 percent of the cities surveyed by APWA in 1975 have a formal operator training program.²⁴ The average initial training period is 54 hours per operator with subsequent training of about 30 hours per operator per year.³⁶ The authors of the above

report on street cleaning recommend that operators be trained not only in how their equipment can best be used and maintained but also in what material needs to be removed and where this is commonly located.¹⁷

Street Improvements - Two actions can be taken to reduce the interference of parked vehicles with street cleaning.

First, signs can be posted along frequently cleaned streets prohibiting parking during specified time periods. This is more important for sweeping than flushing because sweepers must have continuous access to the gutter area to be effective. The second action would improve flushing efficiency, by marking parking lanes or changing curb/gutter configurations to allow the free flow of water and flushed material even in the presence of parked cars.

MUD CARRYOUT CONTROL

Current Mud Carryout Controls

There are currently a variety of means used to control trackout or runoff of mud and dirt onto street surfaces. These methods were discussed briefly in Chapter 1; regulations requiring these methods are discussed in the next chapter.

Optimizing Mud Carryout Controls

For permanent sources of mud carryout (e.g., operations such as ready mix plants, truck terminals, warehouses), it is preferable to select a permanent approach to control. These controls can include paving, oiling, seal coating, or use of nondusting gravel. This minimizes the carryout problem so that it is not necessary to clean adjacent streets.

All of the above controls will produce approximately the same air quality benefit. However, there are other

considerations that would influence the owner or operator's selection: capital cost, maintenance, ability to withstand loads, and drainage and storm water runoff problems.

At temporary sources such as construction sites, it is not possible to deal with the problems by paving, oiling, etc. The data assembled for this report show that the best control approach during the excavation period is immediate cleanup of all mud and dirt carried onto streets to prevent other traffic from spreading the trackout to other streets in the area. A less desirable alternative is to require cleaning of the adjacent streets at the end of each day's work shift. Use of flushers on adjacent streets or any watering control should be undertaken only where it will not create a greater problem of mud trackout.

For most cleared areas, there is a significant problem with runoff onto adjacent streets. At construction sites, contractors use a number of control methods. Such measures are usually implemented in a limited area. However, contractors frequently clear a large area where construction is proposed but may not be undertaken for a number of months or even years. These areas contribute to runoff problems because there is no paving or vegetation to control the soil erosion. The optimum means for controlling these areas is to limit the number of acres cleared and to require control of erosion and runoff by some method of stabilization.

6. LEGAL AND ADMINISTRATIVE ASPECTS OF REENTRAINED DUST CONTROL

There are presently a large number of state regulations and local ordinances that represent control measures for material deposition. In addition, there is considerable diversity in the street cleaning programs utilized by local communities.* The development of regulatory approaches and administrative agreements as mechanisms for legally enforcing control measures is one of the purposes of this document. Some system of intergovernmental coordination would obviously be desirable in view of the existing regulations and street cleaning programs. It is important to find a reasonable means of incorporating reentrained dust control into State Implementation Plans (SIP).

PROGRAMS FOR PREVENTION OF MATERIAL DEPOSITION

Existing State Regulations

In 1971, EPA recommended certain reasonable precautions that could be taken to prevent particulate matter from becoming airborne and these were published in the Federal

* Presentation of legal and administrative aspects of material deposition will precede those on improved street cleaning. Material deposition is more readily handled by regulatory approaches, while street cleaning is usually the responsibility of a local agency and may not be subject to regulation. Although this reverses the order of presentation used in the other chapters, it allows for a more logical discussion in this case.

Register (Appendix B, Section 2.2). Some of these recommendations are actually mud carryout controls and include the following:

- "a. Use of water/chemicals for dust control at sites of demolition, construction, road grading, or land clearing.
- b. Application of suppressants at stockpiles, on dirt roads, or other dust producing surfaces.
- c. Use of hoods, fans, filters, or other containment methods at dust producing operations.
- d. Covering, at all times when in motion, open bodied trucks transporting materials likely to give rise to airborne dust.
- e. Conducting agricultural practices in such manner as to prevent dust becoming airborne.
- f. Paving roadways and maintaining roads in a clean condition.
- g. The prompt removal of earth or other materials from paved streets onto which earth or other matter has been transported by trucking or earth moving equipment, erosion by water, or other means."³⁷

A review of state air pollution control agency regulations reveals 21 states that use portions of the Appendix B recommendations for controlling air pollution from fugitive dust sources. A total of 16 states make use of both paragraphs d and g above, which expressly pertain to the problem of mud carryout.

The Colorado Air Pollution Control Commission has an abatement/prevention measure for unpaved roads and parking areas (mud carryout sources).³⁸ They recommend use of

water, suppressants, shielding, paving, and speed restrictions. They also have control measures for preventing deposits of mud and dirt on improved streets and roads. They require that haulage equipment be washed, wetted down, treated, or covered to minimize dust in transit and loading.

In New York, the air pollution control agency has proposed use of fugitive dust control permits, to become effective January 1, 1980, that would regulate the use of paved or unpaved parking lots and terminal areas.³⁹ The regulation would also require persons responsible for the use of any road not to permit its use unless it is cleaned, treated, and traffic controlled in such manner that visible particulates are not produced.

There are state statutes, implemented by agencies other than air pollution control, that are applicable to mud carryout control. In the states of Massachusetts, Michigan, Minnesota, New Jersey, Texas, Utah, Virginia, West Virginia, and Wisconsin, the administering agency is the highway division. The regulations in these nine states require that anyone operating a vehicle carrying a load on a public highway must prevent that load or any part of it from spilling.⁴⁰ In six of these states, Massachusetts, Michigan, New Jersey, Utah, West Virginia, and Wisconsin, it is also required that loads be securely fastened to prevent leakage and spillage.⁴⁰ None of the state statutes specifically authorize anyone to obtain an injunction to enforce the statute; however, four states (Minnesota, New Jersey, Utah, and Wisconsin) authorize seeking civil remedies and six states (Michigan, Minnesota, New Jersey, Texas, Virginia, and West Virginia) provide for criminal penalties with maximum fines ranging from \$100 to \$1000 and maximum imprisonment from 10 days to 12 months.⁴⁰

Two states offer good illustrations of statewide regulatory programs with regard to covering trucks and controlling mud carryout. North Carolina Highway Commission has a regulation which specifies that "no person operating a dual wheel truck may track or cause mud to be deposited on the paved portion of any state highway, creating a hazard to the traveling public, and such deposits must be immediately removed, under penalty of a misdemeanor."⁴¹ In addition, there is a Highway Commission specification that requires the state's contractor to comply with all state and local air pollution regulations throughout the life of a project, and suspension of work can follow within 24 hours of failure to perform necessary measures of control.⁴²

The second state, Maryland, requires covering at all times for vehicles moving material likely to create air pollution, as well as prompt removal from paved streets of earth or other materials that result from truck or earth-moving equipment or erosion by water.⁴³ Their highway maintenance supervisors and engineers operate a regular schedule of inspection and all violations of the highway code are reported and enforced by the highway patrol. Inspectors require contractors at subdivision developments, shopping centers under construction, and highway construction sites to control such problems with calcium chloride and water trucks and to clean up all spills and trackout.⁴⁴

These state level regulations described above are summarized in Table 6-1.

Existing County and City Ordinances

A number of local ordinances further illustrate possible approaches to mud carryout control. The Polk County (Des Moines), Iowa fugitive dust measure includes the Appendix B wording of both paragraphs d and g relating to truck covering and removal of mud from roadways.⁴⁵ Two additional

Table 6-1. SUMMARY OF STATE REGULATIONS
APPLICABLE TO MUD CARRYOUT CONTROL

State	Air Pollution Control agency Federal model provision ^a			Other regulation	Other state agency regulation
	d.	f.	g.		
Alabama					
Alaska					
Arizona	x		x		
Arkansas					
California				x	
Colorado					
Connecticut	x		x		
Delaware					
Florida					
Georgia	x	x	x		
Hawaii	x	x	x		
Idaho	x	x	x		
Illinois					
Indiana	x		x		
Iowa	x		x		
Kansas					
Kentucky	x		x		
Louisiana	x	x	x		
Maine					
Maryland	x	x	x		x
Massachusetts					x
Michigan					x
Minnesota					x
Mississippi					
Missouri					
Montana				x	
Nebraska				x	
Nevada					
New Hampshire					
New Jersey					x
New Mexico					
New York					
North Carolina					x
North Dakota	x	x	x		
Ohio	x	x	x		
Oklahoma				x	
Oregon	x	x	x		
Pennsylvania		x	x		
Rhode Island					
South Carolina					
South Dakota					
Tennessee					
Texas	x		x		x
Utah					x
Vermont					
Virginia	x	x	x		x
Washington					
West Virginia					x
Wisconsin	x	x			x
Wyoming	x	x	x		

^a see pages 6-1, 6-2.

counties regulate against fugitive dust--Allegheny County, Pennsylvania uses all the provisions of the Appendix B recommendations with the exception of the paragraph on truck covering; and Milwaukee County, Wisconsin uses all the wording of the Appendix B recommendation with the exception of the paragraph on mud removal from roads.^{46,47}

Two cities use the Appendix B recommendations without any modifications--Washington, D.C. and Cincinnati.^{48,49} Several cities have mud control ordinances that require paving of all parking lots. Representative of these is the Rapid City ordinance: "All areas devoted to permanent off-street parking . . . shall be of a sealed-surface construction and maintained in such manner that no dust will result from continuous use."⁵⁰

The city of Seattle has a street use ordinance, No. 90047 (1961), that prohibits deposit of materials on streets.⁵¹ Regulation I, Section 9.15, of the Puget Sound Air Pollution Control Agency, a four-county regional agency in Washington, requires use of water or chemical suppressants at construction sites, parking areas, and roads being cleaned or repaired.⁵² At the end of each work shift, mud and dust on all public roadways has to be removed. The agency also recommends that log storage areas be equipped with truck wash-down facilities so that trucks and log-hauling equipment can be cleaned prior to entry on public roadways. In response to this guideline, some sand and gravel operations in Seattle have installed wheel washes consisting of two parallel spray bars, approximately 25 feet long and 6 inches above ground, activated by an electric eye.

Charlotte, North Carolina has a comprehensive plan for community improvement and their Public Works Department is responsible for making inspections as well as citing violations of mud carryout requirements.⁵³ The maintenance of construction sites is the responsibility of individual

contractors and each employs his own manual labor to take care of this cleanup. There is also a private local firm that is employed to flush streets where the contractor cannot adequately take care of the cleanup. Their construction site ordinance reads as follows: "In the event that dirt, mud, construction materials or other debris shall be deposited upon any street or sidewalk as a result of a construction project in progress, the contractor in charge of the project shall be required to remove said debris. Any contractor failing to comply with this provision shall be assessed a penalty of ten dollars (\$10.00), and each and every day during which such violation continues, shall be a separate and distinct offense."⁵⁴

The Chicago Building Department controls problems of mud carryout at construction sites with requirements contained in the building permit issued to the contractor.⁵⁵ Initially, excavating contractors take responsibility for cleanup of spills and trackout on surrounding streets and use manual labor and brooms to control the problem. Following excavation, some building contractors use street sweepers and subcontract the rest of the work to a hauling company. Others employ street sweepers, motor graders, and prepare all construction sites and haul roads with fragmented brick to control both dust and runoff problems.

Kansas City, Missouri prohibits mud trackout and requires covers for trucks hauling materials to and from construction sites. These two ordinances, Sections 34.145 and 34.148, are enforced by the Street Department, which is concerned primarily with concrete or sand spills on city streets.⁵⁶ Local contractors use coarse gravel to prevent mud buildup between truck tires and sometimes use broom sweepers and vacuums on streets adjacent to their sites.

Kansas City, Kansas prohibits overloading trucks, spilling from trucks, or leaving construction materials on

streets.⁵⁷ Their ordinance is also under the jurisdiction of the Public Works Department and it carries a maximum penalty of \$500 and/or 30 days imprisonment.

Enforcement Procedures

The extent of enforcement of control measures for reducing material deposition on streets is difficult to ascertain. The information gathered for this report indicates that responsibility for inspection and enforcement is usually delegated to a division within the city public works department or within the state highway department. There is uneven enforcement of the Appendix B type regulations by state air pollution control agencies.

While all agencies respond to complaints if an ordinance is violated, some rely on a team of inspectors to watch for violations and to deal with those that occur. The usual procedure is to notify the person in charge that an ordinance is being violated and to give him a number of hours to comply with the request. Where cooperation is not obtained, there are a variety of steps taken to bring about compliance.

Of the cities cited in the above section, several were contacted to determine how they enforce their ordinances. These findings are presented in Table 6-2. If these agencies offer a fair representation of practices nationwide, it appears that the most common and effective procedures are systematic inspection, notice of request for compliance, and enforcement through a fine or billing for cleanup done by the city or state.

The most critical components of an enforcement program are frequent inspection (perhaps in coordination with the local air pollution control agency) and a penalty for lack of compliance that is large enough to make it worthwhile to comply with the law.

Table 6-2. ENFORCEMENT OF LOCAL ORDINANCES
FOR CONTROL OF MUD CARRYOUT

City/ Population	Agency enforcing	Type of ordinance	No. of citations, annual	Manpower within department ^a	Enforcement procedures
Charlotte/ 241,000	Community Improvement Div	Ord requires cleanup of dirt and debris from const; ord requires truck cover- ing	23 issued in 1976 const contractors	Division supervisor plus nine inspectors	Get compliance by inspections at all sites, request for cooperation; ord for truck tarping enforced by Police Dept
Chicago/ 3,367,000	Dept of Bldg; Bldg Permits, Adm Svcs Office	Bldg per- mits; anti- litter ord	Depends on weather con- ditions; daily viola- tions during wet weather	53 inspec- tors (this ord is one of many ord included in daily in- spections); there are 60,000 const per- mits issued annually as well as permits for utility work, which also would create mud carryout	Bldg permit requires ad- jacent streets be kept clean; a site is shut down, where the contractor does not comply, un- til he arranges to control the problem with a wheel wash and with sweepers, if necessary
Kansas City, Kansas/ 168,000	Street Dept	Ord prohib- its truck spillage and prohibits const ma- terials being left on streets	-	-	This ord is en- forced only if complaints are received by the Police Dept or the Street Div
Milwaukee/ 717,000	Bureau of Street San- itation	Ord requires truck tires be cleaned; prohibits all dirt and debris on streets	2 to 3 court actions in 1976	9 super- visors (on an 8 mo-- Apr thru Nov--opera- tion) who inspect and handle vi- olations	Police Dept closes down const site un- til compliance is achieved; all violations at a site where const is halted are fined \$500/ day and, in addi- tion, a traffic violation is issued against each truck that continues to operate from the site
Rapid City/ 48,000	Streets and Sanitation	Ord prohib- its deposit of materials on streets and requires cleanup	Daily vi- olations whenever it rains or snows (30% of the time contractor cleans; 70% of the time the city cleans and bills the contractor)	3 foremen (to in- spect) and 5 street sweeper operators to clean	Have ord against both contractors littering streets and gravel trucks spilling loads; there is citizen cooperation in identifying vi- olations and good cooperation from sand/gravel owners; city also cleans all mud runoff from streets in low lying areas after rain/snow
Rapid City/ 48,000	Building Inspection	Bldg permit requires sealed-sur- face const and mainten- ance for all off-street parking areas		5 Building inspectors and 4 from the Eng and 1 from the Fire Dept	Bldg permits for control of all parking lots; ord requires surface sealing; very few unsurfaced lots (they use dust preventives on these during the summer)
Seattle/ 531,000	Engineers Office	Street use ord	Daily vi- olations	13 inspec- tors	Use a bond/de- posit system

^a Total manpower within the department; responsible for inspection and enforce-
ment of other ordinances in addition to the mud carryout controls shown.

It is necessary to have a team of inspectors (two or more depending upon the size of the city) who can make daily or every other day inspections of the entire community. Some cities have a grid system and assign a single grid to each inspector. The department responsible for inspection and the manpower employed varies among cities. As shown in Table 6-2, the provisions for mud carryout control are usually contained within a building permit and thus are the responsibility of the building department, or they are street use ordinances and are enforced by the street department.

The three cities shown in Table 6-2 with the strictest enforcement procedures are Milwaukee, Chicago, and Seattle. In Milwaukee, the \$500 daily fine is large enough that payment of the fine is more costly than complying with the ordinance.⁵⁸ When the stop order is issued to halt construction, every truck that continues to operate from the site is also in violation of a traffic ordinance and is fined. Compliance requires that the contractor use a designated route to and from his site and that he keep the route clean with mechanical sweepers. At the large construction sites, contractors must also build a coarse gravel road for use by their trucks to shake debris from the undercarriages.

In Chicago, the building permit issued at the time construction is begun requires the contractor to control mud carryout.⁵⁹ This usually involves a steel mesh decking at the entrance to the site where truck wheels are hosed off, and the "barricade permit" allows the contractor use of adjacent streets for the period of construction as long as he employs a street sweeper to keep the streets clean. Chicago does not fine, since a stop order is issued where contractors fail to comply with the provisions of their building permit.

In Seattle, control is obtained with a bond/deposit system where the contractor posts a bond with the city.⁵¹

If the contractor fails to meet any city requirements for maintenance of his site, the city performs the work and bills the service against the deposit.

Model Regulations

Two control measures were discussed in Chapter 3 that have potential for improving air quality--control of dirt and mud carryout from major sources and control of dirt and mud carryout from ubiquitous sources. A model regulation for implementing these two measures would include the following provisions:

Major mud carryout sources

- ° Manual or mechanical sweeping of streets adjacent to major sites, preferably with immediate removal of material deposited on streets or a cleanup at the end of each work day.
- ° Use of a ground cover or chemical dust suppressant for sites to control runoff and trackout.
- ° Addition of a coarse gravel road on construction sites for trucks to drive over and shake loose debris from the vehicle undercarriage.
- ° Wheel wash mechanisms for vehicular construction equipment and for tractor trailers at terminal sites.
- ° Truck tarping or required wetting of the load.
- ° A limited number of cleared acres at any one time in a given area unless soil erosion control measures are included.
- ° Some method of soil control for cleared areas where development of the area is delayed.

Ubiquitous mud carryout sources

- ° A maximum number of vehicles using a parking area unless it is paved.
- ° Required application of seal coating or oiling for parking areas used by fewer vehicles.
- ° Oiling or seal coating for unpaved driveways and road shoulders.

Intergovernmental Coordination

If regulations such as those cited above are to be included in SIP's, then some clearly defined mechanism for the cognizant air pollution control agencies to coordinate enforcement of that existing regulation with the non-air pollution control agency must be established. The state has to incorporate in its implementation plan the necessary mechanisms for reducing reentrained dust. They must then delegate the implementation of these specific mechanisms to local agencies. In most cases, this would mean the municipal public works department.

If the state agency is not going to pass mud carryout regulations and depends on another agency to enforce such regulations, then establishment of some kind of administrative agreement for inspection and enforcement would probably be necessary.

PROGRAMS FOR IMPROVED STREET CLEANING

The Concept of an Administrative Agreement

Regulations requiring municipalities to adopt specific street cleaning practices for air pollution control purposes would probably be unsuccessful, principally because present knowledge of controls for reentrained dust are insufficient to define in general regulatory terms the optimum street cleaning program for a city. As an alternative to regulation, the use of an administrative agreement between the state air pollution control agency and the local government is proposed. Through this agreement, the local government would be committed to institute changes in street cleaning practices in order to improve particulate air quality.

The term "administrative agreement" as used herein refers to a written agreement entered into by two or more governmental units. Such an agreement would constitute a

formal, but not necessarily legally enforceable, commitment by one governmental unit to engage in a specific set of activities. It would consist of a statement of local governmental policy regarding street cleaning and air pollution control and a plan by that body to implement programs, including any necessary budgetary adjustments. A timetable for implementing the actions would also be specified in the written agreement. An example for this type of agreement is presented in Figure 6-1.

There has been no indication whether such a nonregulatory approach would be approvable by EPA if submitted as part of an SIP revision. The Federal regulations (40 CFR 51.11f) do allow the state to delegate authority *to carry out* part of the plan:

The State may authorize a local agency to carry out a plan, or portion thereof, within such local agency's jurisdiction: Provided, that such plan demonstrates, to the Administrator's satisfaction, that such local agency has the legal authority necessary to implement such plan, or portion thereof, and further: Provided, that such authorization shall not relieve the State of responsibility under the Act for carrying out such plan, or portion thereof.³⁷

The municipalities certainly have legal authority to clean their streets. The uncertainty arises in whether every measure identified in the control strategy must be backed by a regulation. Also, the state has no basis for seeking injunctive relief for nonperformance by the municipality and has no legal authority for cleaning the streets if the municipality fails to do so.

No precedents for comparable situations to this could be found in other EPA regulatory areas. The agreement shows recognition of the state agency's objectives and an intent to comply with program requirements that are not as yet defined because they must be designed specifically for each municipality.

THIS AGREEMENT made and entered into on this the _____ day of _____, 19 ____, by and between the STATE of _____, hereinafter referred to as the Party of the First Part, and the CITY OF _____, a municipal corporation organized and existing under and by virtue of the laws of the State of _____, hereinafter referred to as the Party of the Second Part.

WITNESSETH:

That, WHEREAS, the parties hereto recognize that there is a great need on the part of their citizens for a program and/or system for controlling dust from paved streets and parking facilities affecting air quality within the jurisdictions of the party of the first part and the party of the second part; and

WHEREAS, the party of the first part has found that the institution of a program and/or system for controlling air pollution from paved surfaces is necessary in order to achieve the intents and purposes of the State Air Pollution Control Implementation Plan; and

WHEREAS, the party of the second part is desirous and willing to define and implement policies and execute programs which will produce effective control of dust from paved surfaces owned and operated by the party of the second part.

NOW, THEREFORE, in consideration of the premises and in the further consideration of the mutual agreements and covenants hereinafter contained, the parties hereby enter into the following agreements:

1. The party of the second part is authorized by the party of the first part to carry out those portions of the State Air Pollution Control Implementation Plan relating to control of dust from paved streets within its jurisdiction.
2. It is agreed that the party of the first part, acting through its Department of Environmental Protection, will provide technical assistance to the party of the second part in defining the degree and extent of fugitive dust control required on paved surfaces within the boundaries and jurisdiction of the party of the second part.
3. It is agreed that the party of the second part will within two months of the date of this agreement adopt a resolution stating that it is the policy of the party of the second part to modify street cleaning practices to meet air quality objectives; within six months of the date of this agreement specify and submit to the party of the first part a detailed program for implementing said policy, which program shall include such elements as both parties agree to be necessary; and at the time of the next following budget approval submit to the party of the first part an operating budget and capital expenditures budget which provides the fundings necessary to implement the programs so developed.
4. It is agreed that the party of the first part and the party of the second part will equally share the expense of determining the degree and extent of dust control required, and that the party of the first part will assist the party of the second part in finding supplementary sources of funding to implement the programs developed as a part of this agreement.

IN TESTIMONY WHEREOF, the parties hereto have caused this agreement to be executed, in duplicate, by their duly authorized agents and/or officials, as of the day and year first above written,

ATTEST:

STATE OF _____

Recorder

By _____

Executive Director,
Department of Environmental
Protection

ATTEST:

CITY OF _____

Clerk

By _____

Mayor

Figure 6-1. Example administrative agreement.

Development of an Administrative Agreement

There are five basic elements to the process of developing the type of administrative agreement discussed herein:

- ° decision by the air pollution control agency that improved street cleaning is necessary in order to attain and maintain air quality standards;
- ° establishment of a joint institutional mechanism with the public works department to define the nature of such improvements;
- ° provision of active technical assistance on the part of the air pollution control agency;
- ° adoption of altered street cleaning practices as a matter of local governmental policy;
- ° development of program elements designed to implement and assess those desired improvements.

The first of these is amply discussed in other portions of this report and need not be discussed further here.

Institutional Mechanisms - Modifications to the street cleaning program determined independently by the air pollution control agency have no better chance of being implemented than equivalent regulations adopted by the agency. Rather, what is required is an institutional process for agreeing upon changes that can be fitted into the existing street cleaning operations with the optimum mix of minimized change and maximized air pollution control effectiveness.

It is suggested that a committee comprised of representatives of both organizations be appointed to determine the technical means of achieving the desired degree of improvement in air quality. This committee process might be rather difficult to implement in practice due to differing organizational imperatives.

Technical Assistance - A public works department cannot be expected to know what must be done to reduce the air quality impact of reentrained dust from paved streets. Nor can an air pollution control agency be expected to know what must be done to clean streets efficiently and effectively. Each group must work with the other, as is implied by the administrative agreement concept, to determine what must be done to produce mutually desirable results.

To this end, the air pollution control agency needs to provide three services: guidelines as to what equipment and procedures are most beneficial in terms of air quality; directions as to what parts of the municipality are most in need of improved air quality; and air quality sampling data which can be used to monitor and assess the effect of modifications in the existing street cleaning system.

Municipal Policy Development - In making policy decisions that add, delete, or modify community objectives, municipal administrations are usually responding to public pressure, special interest groups, perceived need by the administration itself, or consideration of requirements or desires of other governmental entities. The municipal administration must determine the likely costs and benefits of the improvements in air quality that can be expected from altered street cleaning practices and where and how the necessary modifications in activities and expenditures are to be made. Once these questions have been satisfactorily answered the municipal administration can then draft a resolution stating the policy to be followed and submit it to the city council for a vote under its prescribed rules of ratification. Wording of the resolution in each municipality will vary, but may approximate the model shown in Figure 6-2. Following favorable adoption of such a resolution, administrative and other legislative actions will be required to implement

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BY THE COUNCIL:

WHEREAS, this Council has, through the State Department of Environmental Protection, become aware of overall air quality plan objectives for the State and this municipality; and

WHEREAS, this Council recognizes that national air quality objectives are embodied in the State objectives; and

WHEREAS, this Council also recognizes the need to modify street cleaning practices in order to meet air quality objectives and protect the health and welfare of the citizens of this municipality; and

WHEREAS, this Council has been advised that by reordering public works expenditures and procedures and modifying existing powers and programs that this municipality can achieve a significant measure of air quality improvement through control of recentrained dust;

NOW THEREFORE, BE IT RESOLVED by the Village/City Council of this municipality, that program plans and implementation be directed toward a systematic modification of street cleaning practices;

BE IT FURTHER RESOLVED that the Department of Public Works is directed to cooperate with the State Department of Environmental Protection to define jointly the nature, degree, and extent of those modifications which are necessary to implement this policy; and

BE IT FURTHER RESOLVED that the Clerk of this Council is hereby directed to certify copies of this resolution to Village/City Directors of Public Works, Office of Budget, and Community Planning for program planning and execution.

ADOPTED at a regular meeting of the Village/City Council of Any County, Every State this _____ day of _____, 19____.

Council-Person	_____	AYE	_____	NAY
Council-Person	_____	AYE	_____	NAY
Council-Person	_____	AYE	_____	NAY
Council-Person	_____	AYE	_____	NAY
Council-Person	_____	AYE	_____	NAY

CERTIFICATE OF CLERK

IT IS HEREBY CERTIFIED that the foregoing is a true and correct transcript of a resolution adopted by this Council in session the _____ day of _____, 19____.

IN WITNESS WHEREOF, I have hereunto set my hand and affixed the official seal of the Village/City Council of Any County, Every State this _____ day of _____.

Clerk
Village/City Council

Figure 6-2. Example city council resolution.

the policy. The first administrative step involves program planning and development.

Program Planning and Development - Programs are action-oriented media for carrying out policies. The increasing complexity, number, and technical character of municipal problems makes it necessary that program planning be accomplished in a systematic manner. Moreover, the multiplicity of municipal needs that compete for funds makes it imperative that any new program or major program modification be well-conceived and well-presented.

Programming provides the framework for rational decisions. This framework may be categorized into assessing existing programs, determining where these programs can be most effectively applied, identifying new areas of concern, designing new programs, and scheduling new programs.

Programming options for controlling dust from municipally-owned paved surfaces are largely limited to public works or street cleaning functions and activities. To achieve improved reentrained dust control may require improved maintenance of existing street cleaning equipment, purchase of new or different equipment, improvement of employee training programs, more frequent street sweeping, and/or modifying the specific sequence of activities in a given area. It may be desirable to program joint agreements with neighboring jurisdictions. In addition, programs related to Areawide Waste Treatment Management Planning (Section 208, P.L. 92-500) requirements may need to be integrated with those related to air quality.

According to the International City Manager's Association (ICMA),⁶⁰ there are four basic ingredients to the actual process of developing street cleaning programs:

- ° adequate planning maps,
- ° definition of desirable frequency and time of cleaning for individual streets,
- ° development of routes, and
- ° scheduling control.

The air pollution control agency should obtain enough of this type of information from the public works department so that the agency can interactively determine with the department what modifications need to be made as a part of the effort to reduce reentrained dust from paved surfaces.

Budgeting Mechanisms - Implementing the changes agreed upon during the process of program development will require modifications in the budget that would otherwise be prepared. Such modifications may include the same budgeting mechanisms as used for other municipal functions: the annual operating budget and the capital improvements budget.

A reordering of existing budget priorities may be necessary. For example, if more frequent cleaning is required in a specific part of the municipality, then either services will be cut back in other parts of town, productivity will increase, funds will be shifted to the public works department from other departments, or an increase in overall financial resources will be obtained. These alternatives clearly imply that a thorough analysis of how the requisite changes can be implemented most efficiently is required. Likewise, additional street cleaning equipment may have to be purchased. The air pollution control agency must make every effort to provide the public works department with the best possible information concerning the air pollution control effectiveness of different types of street cleaning equipment.

Any effort to improve street cleaning practices will have to be conceived with recognition that funding sources

for local governments are limited and that the fundable improvements must first be incorporated in the next year's approved budget, which would prevent very rapid implementation.

Evaluation of Program Effectiveness - The concept of "effectiveness" refers to the degree to which a desired result is achieved. Thus, there are two types of effectiveness measurements that should be developed and assessed:

- effectiveness in improving air quality, and
- effectiveness in implementing the program elements determined to be necessary to improve air quality.

According to the ICMA and APWA, there are no generally accepted ways of measuring changes in cleanliness of streets.^{60,61} Therefore, the air pollution control agency and the public works department will have to agree upon some mutually satisfactory indicators of effectiveness that can be used. Some possibilities include:

- volume of material collected,
- miles of streets swept,
- curb-miles of streets swept,
- tons per curb-mile swept, or
- any other mutually agreeable unit of measurement.

Given the fact that the desired changes will probably focus upon frequency of cleaning in a given area, it is suggested that the most useful indicator would be curb-miles swept by area.

In the end, however, the true measure of the effectiveness of the discussed changes will be air quality impact. It is important that the agency design an adequate monitoring network and reporting procedures to the public works department so that changes in air quality can be correlated with changes in street cleaning practices.

IMPLEMENTATION

The preceding two sections have described the legal and administrative elements of controls based on preventing material deposition and improving street cleaning. Table 6-3 summarizes these control measures, possible implementation methods, and an estimate of the length of time for each to become operational. Except for improved street cleaning, implementation would require the adoption of a state regulation or a local ordinance.

In the case of controls for major mud carryout sources, implementation can be accomplished in one of two ways. Either the state air pollution control agency can enforce the measures or the responsibility can be delegated (within the SIP) to a local agency, possibly a municipal building inspection or public works department. Where the state is responsible, they will need sufficient personnel to regularly inspect all major sites. One or two years is probably sufficient time to effect this type of regulation.

If a local agency is the responsible party, the municipality will need to pass ordinances to implement each measure. For major but temporary sources, such as construction sites, control could probably be a provision of the building permit or zoning permit issued to the contractor. Because the control measures suggested can require purchase of equipment (street sweepers) or arrangements for site maintenance (wheel wash mechanisms for trucks), a time period of one to two years may be required. This allows contractors the lead-in time necessary for compliance.

For major permanent sources, such as ready-mix plants, truck terminals, etc., the local air pollution agency could require operators of problem sources to submit a compliance plan on how they intend to control trackout and then issue an enforcement order when the compliance plan is approved.

Table 6-3. IMPLEMENTATION OF CONTROL MEASURES

Description of control measure	Party involved	Method of implementation	Estimate of time required
<u>Control of major mud carryout sources</u>			
Construction sites, truck terminals, etc.			
ground cover	Contractor, private owner	Local street ordinances, provision of local building permit, or air pollution control agency regulation	1-2 years, possibly as much as 5 years if some sort of compliance plan were involved for privately-owned source
chemical suppressant			
building of coarse gravel road			
tire wash mechanism			
tire scrapers	Const equip mfg	Federal legislation	
truck tarping	Contractor, state or local agency	State highway regulation and/or local ordinance	
wetting of aggregate loads	Contractor	State highway regulation and/or local ordinance	
number of acres under const	Contractor	Local building permit or zoning ordinance	
soil erosion for any cleared area	Contractor	Local building permit or zoning ordinance; air pollution control agency regulation	

Table 6-3 (continued). IMPLEMENTATION OF CONTROL MEASURES

Description of control measure	Party involved	Method of implementation	Estimate of time required
<u>Control of ubiquitous mud carryout sources</u>			
Unpaved parking lots	Private owner	Local building permit or zoning ordinance; air pollution control agency regulation	3-5 years
Unpaved driveways	Private owner		
Unpaved road shoulders	State or local agency	Local street ordinance; air pollution control agency or state highway regulation	Phased control over a period of years
<u>Control by improved street cleaning</u>			
More frequent use of flushers on major arterials	Local street departments	Require reallocation or revision of street cleaning priorities; budget approval, if equipment has to be purchased or if it increases the total workload	1-3 years
Use of flushers in combination with pickup equipment			
Frequent street cleaning following sanding/salting operations			
<u>Operator training</u>			
On-street parking restrictions	Local street departments	Require a street use ordinance and budget approval for signing	1-3 years
Modifications to curb/gutter configuration	Local street departments	Require budget approval for curb and gutter construction	1-3 years

A provision for this type of enforcement action would also require a local ordinance and a time period of one to two years.

Controls for ubiquitous mud carryout sources involve both municipal and private property. Unpaved road shoulders are usually within the jurisdiction of the state or local agency and control could reasonably be phased over a period of years. Control of other sources, such as unpaved parking lots and driveways, usually involves private ownership. Passage of the necessary ordinances and allowance of time for implementation would probably require three to five years.

In the case of control by improved street cleaning, there are apparent air quality advantages to be gained with frequent use of flushers on major arterials, use of a combination flusher/pickup method, and the prompt removal of sand or salt throughout winter months. If the state air pollution control agency provides the local public works department with an understanding of the air quality benefits that each measure offers, then the municipal department can redesign its existing street cleaning program to incorporate these measures. This could be undertaken on a test basis, over a three to six month period, to give both agencies involved an opportunity to make necessary modifications. Where the recommended measures involve expanding the program to include more frequent cleaning, to cover a greater area of the city, to purchase new equipment, to increase the department's staff, or to train operators in the optimum use of their equipment, more time would be required for implementation. Budget approval, selection of equipment, requests for bids, placement and receipt of orders is a lengthy process but a time frame of one to three years is realistic. Phasing in new equipment by replacing worn units over a period of five years is a practical approach and is a current practice in most municipalities.

As outlined above, it is apparent that implementing some of these control measures will involve not only considerable time but possibly increases in personnel. There is also the problem of establishing a measure of intergovernmental coordination between the cognizant agencies. The coordination between a state air pollution control agency and the municipal public works department for setting up a mutually beneficial street cleaning program has already been discussed in detail in this chapter. With coordination between the two agencies, it is possible that the increases in personnel required can be shared on an optimized basis. Where trained employees already exist, as in the building and zoning sections of public works departments, they can perhaps include some of the inspections in their regular assignments. For example, in Seattle the street department's maintenance foremen cover the area daily and radio any violations of the city's street use ordinance to their inspectors. It is possible such an intradepartmental procedure can be followed on an interagency level.

One further phase of implementation concerns the technical difficulties that some of the recommended control measures might cause. For example, use of tire wash mechanisms that are improperly placed can cause mud carryout instead of minimizing it. The use of tire scrapers that are not properly adjusted can cause excessive tire wear. Where operators of street cleaning equipment are not fully informed of the optimum removal techniques, considerable material critical from an air or water pollution aspect can be missed. Coordination between the state and local agency can minimize these difficulties.

PUBLIC ACCEPTABILITY

Because successful implementation of any of the controls is contingent upon the support it would receive from members

of the community, an effort was made to determine public acceptability for such measures. With the cooperation of the Kansas City, Missouri Action Center, citizen response to the subject of improved street cleaning methods was examined. The Action Center records each call received on a service request form. A total of 170 street service requests were reported in a three-year period (1974 to 1976). A review of these requests showed that only a few citizens were concerned with the general street cleaning program. About 90 percent of the calls were requests for litter removal from the neighborhood street. One instance of citizen interest was noted where an individual called to suggest that the city post signs 24 hours prior to street cleaning so that cars could be moved for more thorough sweeping.

In the spring and summer of 1976, a total of 626 persons were contacted throughout the city in a citizen attitude survey on the subject of city government and the services it provides. On questions relative to condition of city streets, respondents did not include need for additional street cleaning as an existing problem. The list of problems with streets, in order of frequency mentioned, included the following:

- ° chuck holes
- ° overhaul/widening needed
- ° improper snow removal
- ° rough streets
- ° poor surfacing
- ° problems with curbing
- ° trash in streets
- ° repairmen leaving holes

Trash on streets was low on the list of priorities and general cleanliness of streets was not mentioned at all.

In an interview with three city councilmen, citizen attitude regarding the street cleaning program was explored further. Their responses substantiated much of the input received during the city's 1976 citizen survey. They did not feel that there was a problem with the existing program. They believed that it should serve an aesthetic purpose and they were particularly concerned that it be vigorously carried out in the central business district. They also felt that the primary effort in cleaning should be directed at removing litter, large spills of mud or sand, and any accumulation of leaves around catch basins.

Based on the above three indications of public sensitivity to street cleaning, it does not appear that the general public is concerned about street cleanliness other than in those instances where street litter is aesthetically unpleasing or poses a safety hazard. It is not possible to generalize from this single example, but it is obvious that citizen concern would be helpful in promoting an expanded street cleaning program.

7. PROCEDURE FOR DEVELOPING A CONTROL STRATEGY FOR REENTRAINED DUST

Five measures for control of reentrained dust from paved streets have been identified and described in this report. A procedure for developing a control strategy containing one or more of these measures would have a number of major steps. Some of these steps were discussed in detail in preceding chapters. The steps are presented below as a systematic procedure for implementing an effective control strategy:

1. Define the Problem Area

The first step is to define the area exceeding particulate air quality standards and the approximate contribution from vehicle-related emissions in this area. Many of the studies which have already identified reentrained dust as an important source category (references 3 through 14) can be used for examples of how to inventory and estimate the air quality impact of reentrained dust. The control strategy should be designed to have its effect concentrated in the non-attainment area, although individual control measures may be implemented on a city-wide basis.

2. Determine Street Cleaning Practices and Locate Major Mud Carryout Sources

It is important to know the existing level and type of street cleaning to which modifications might be made. Also, the overall efficiency of the existing program should be evaluated, since an increase in budget or manpower in a

poorly administered program would not translate into a significant reduction in particulate concentrations. A survey of sources contributing to street loadings in the area is a prerequisite to selection of effective control measures.

3. Design Modifications in the Street Cleaning Program

In conjunction with the public works department, several alternative changes should be reviewed. At least two should be designated for further investigation--one which is expected to produce the maximum air quality impact and one which will probably result in a substantial air quality impact with a minimum expansion of the existing street cleaning program. The proposed changes should describe types of equipment to be used, cleaning frequencies by street type and area of city, weekly equipment-hours and curb-miles by area of city, projected personnel requirements, and comparable data for the existing program. The air quality impact can only be estimated approximately and would probably be based on the expected percent reduction in emissions and the present contribution of vehicle-related emissions to air quality in the affected area. There are no regional-scale atmospheric dispersion models for particulate currently available to assess the effect of reentrained dust emission reductions on ambient concentrations.

4. Consider Control Measures for Preventing Material from Reaching Street Surfaces

If the survey of the non-attainment area reveals that there are identifiable mud carryout sources, a regulatory approach or municipal program for control of carryout should be considered. At this point in control strategy development, it would only be necessary to identify the specific types of carryout sources to be covered by the proposed

program (e.g., unpaved parking areas, unpaved shoulders, construction sites), time period for its implementation, and its effect on average street loadings and air quality.

5. Determine Estimated Costs, Public Acceptability, and Adverse Environmental Effects

Fairly detailed descriptions of each control measure would be needed in order to prepare a cost estimate. The experience of the public works department should be utilized extensively in compiling and selecting cost data. Public acceptability may be based on the city council's agreement to modify the street cleaning program. Adverse environmental effects should be identified by conferring with the 208 agency and others involved in environmental quality and control.

6. Calculate the Cost-Effectiveness of Individual Control Measures

From the data generated in the steps above, the cost-effectiveness of each measure can be estimated directly. Any measure with substantially higher costs per unit reduction in particulate concentrations should be reviewed for possible replacement, elimination, or modification to make it more cost-effective. The group of measures in the final strategy should be capable of attaining the ambient standards in the area defined in the first step or should contain all reasonable measures expected to reduce concentrations in that area.

7. Design a Demonstration Program

A further step that would be worthwhile in developing a control strategy, but one that is not necessarily essential, is to design a demonstration program (pilot study) for a smaller area. The proposed street cleaning or mud carry-out controls could be tested and air quality impact observed

within a limited area. Because of inconsistent results from the field studies performed to date to evaluate control measures for reentrained dust, this step would enable the public works department to test any strategy to reduce reentrained dust emissions prior to full-scale implementation. If possible, the test program should be conducted with existing street cleaning equipment and manpower or, in the case of mud carryout controls, with controls in the demonstration area being implemented by the public works department. This testing could be done while funding and approvals for the full-scale program were being obtained.

As soon as more definitive data on the effectiveness of reentrained dust controls become available, this demonstration program may not be required and the public works agency could implement the full-scale program directly.

8. Obtain Funding and Approval for the Full-Scale Program

This step would include incorporation of the proposed modifications into the budget approval process and the passage of necessary ordinances or state regulations. In certain cases, the funding could be contingent on the successful demonstration of an air quality impact in the test area. It is anticipated that this step would require approximately one year.

9. Optimize the Control Program

If the demonstration program for a smaller area is undertaken, there may be some instances where the results of the study suggest adjustment in the design of the street cleaning or the proposed mud carryout controls. Prior to implementation of the control strategy, there should be an opportunity for findings from the study to be analyzed and used to adjust any elements of the strategy.

10. Monitor the Full-Scale Program to Assess its Air Quality Impact

It is important that the ambient sampling network in the non-attainment area be able to adequately determine the effect of the reentrained dust controls. This may require the addition of some sampling stations to the regional network for a period prior to and after implementation of the strategy, until its impact has been established.

8. RECOMMENDATIONS FOR FURTHER STUDY

This document represents the first comprehensive examination of control techniques for reentrained dust, so it is anticipated that many more detailed studies will follow. Some potentially productive areas of investigation which were identified during preparation of the present document are:

1. A field study which measures the air quality impact of *daily* street cleaning, especially flushing, on high traffic volume streets. There are several design considerations which should be incorporated in any such study:

- ° At least one control site with a similar exposure should be located near but outside the cleaning area.
- ° Particulate samples should be taken daily and possibly for even shorter time periods.
- ° Traffic counts should be taken for periods concurrent with the particulate samples.
- ° Wind speed and direction measurements should be made in the street canyon area.
- ° Rainfall records should be kept, including the hours of rain.
- ° Detailed records of the street cleaning operations should be kept--time, weight of material removed (if applicable), any problems with cleaning equipment.
- ° Seasonal changes in the amount and type of material on streets should be accounted for in scheduling alternative cleaning methods.

2. A more detailed study of the potential applicability of vacuum sweepers. Although vacuum sweepers had good street cleaning capabilities and ability to remove fine particles from street surfaces, their use failed to reduce particulate concentrations. Manufacturers of vacuum street cleaning equipment would probably cooperate in a demonstration project to test operating or mechanical modifications that would reduce air pollution levels. Possibly an industrial-size vacuum cleaning unit with a cloth filter on the air discharge could be tested along with a municipal-size vacuum cleaning unit to determine whether discharge of fines reduces the effectiveness of the larger units.

3. An evaluation of several non-conventional street cleaning techniques, such as regular winter street cleaning or sweeping traffic lanes as well as curb areas.

4. Liaison and cooperative field work with construction industry trade associations on reasonable methods to minimize mud carryout from construction sites. There would be no need for ambient air sampling in such a study; a good method for measuring the amount of material tracked from the sites would provide a better measurement of effectiveness.

5. Development of a street loading measurement procedure that is accurate, representative of a long section of the street, replicable, and that can be performed by technician-level personnel. The American Public Works Association is also very interested in developing such a procedure.

6. Further investigation of the relationship between street surface loadings and vehicle-related emission rates. The project field studies showed no correlation between these two variables, but another EPA-sponsored study concluded

that they were directly proportional.¹⁵ Some definitive research on the effect of street loadings on reentrained dust emission rates is needed.

7. Particulate emission tests of motor vehicle exhaust. There were several indications that a significant portion of the vehicle-related air quality impact was from direct emissions rather than reentrained material: 40 percent of the material was combustion products; the emission rate decreased with increasing vehicle speed; and there was no correlation between street loadings and downwind concentrations. The current EPA-recommended particulate emission factor⁶² of 0.34 g/veh-mi for light-duty vehicles is based on only a single testing study.⁶³ Therefore, confirmation of this value appears to be warranted.

8. Adaptation of a line source model such as APRAC or HIWAY for modeling of suspended particulate. Since vehicle-related emissions account for such a high percentage of suspended particulate emissions in urban areas, a much more accurate representation of the geographic distribution of these emissions is needed than provided by currently available area source models. A fallout function should be included in this line source model.

CHARACTERISTICS OF REENTRAINED DUST

The project field studies yielded much information on the factors which affect reentrained dust emission rates. That information is summarized in nine separate sections in this appendix.

CONCENTRATION GRADIENTS

The profiles of short-term average particulate concentrations away from a street were demonstrated to be quite similar to those for carbon monoxide, and can be approximated by a Gaussian line source model.* However, for the longer averaging times of interest with particulate concentrations (24-hour or annual average), changing wind directions and relatively high "background" levels tend to reduce concentration gradients in the vicinity of streets. There are two contrasting, idealized traffic patterns which produce distinctive particulate concentration gradients near streets:

- ° A single high traffic volume street or expressway with almost no traffic on other streets in the surrounding area.
- ° A grid network of evenly spaced streets all of which have approximately the same traffic volumes.

* Use of the line source dispersion equation to estimate vehicular emission rates is discussed starting on page A-15.

These two situations and resulting concentration profiles are shown in Figure A-1. For the first traffic pattern, the concentration measured at any point is highly dependent on the distance of that point from the street. The contribution added by emissions from the street can be roughly estimated to be inversely proportional to distance from the street ($y \approx \frac{a}{x + b}$, where a and b are constants). In an area with a dense network of streets, concentrations are relatively independent of distance to the nearest street because proximity to one street increases distances to other surrounding streets which also contribute to the total concentration at that location. Most urban areas have traffic patterns and street networks that combine the characteristics of these two idealized examples, so moderate concentration gradients with increasing distance from the street would be expected.

TRAFFIC VOLUME

In field studies performed to provide data for this document, a well-defined relationship between traffic volume and measured concentrations was observed. At the location where the most traffic counts and air quality measurements were available for simultaneous time periods, a correlation of 0.8 for these two variables was found by linear regression analysis. Within the entire range of traffic volumes occurring on this street, the relationship appeared to be linear, as shown in Figure A-2. Therefore, the assumption made in using emission factors for reentrained dust from motor vehicles--that total emissions are directly proportional to traffic volume--is borne out.

Although concentrations at a site near any one street appear to vary quite closely with that street's traffic volume, the added concentration per vehicle is not consistent from one location to another. Comparison of the data in Table A-1 for two different streets demonstrates this

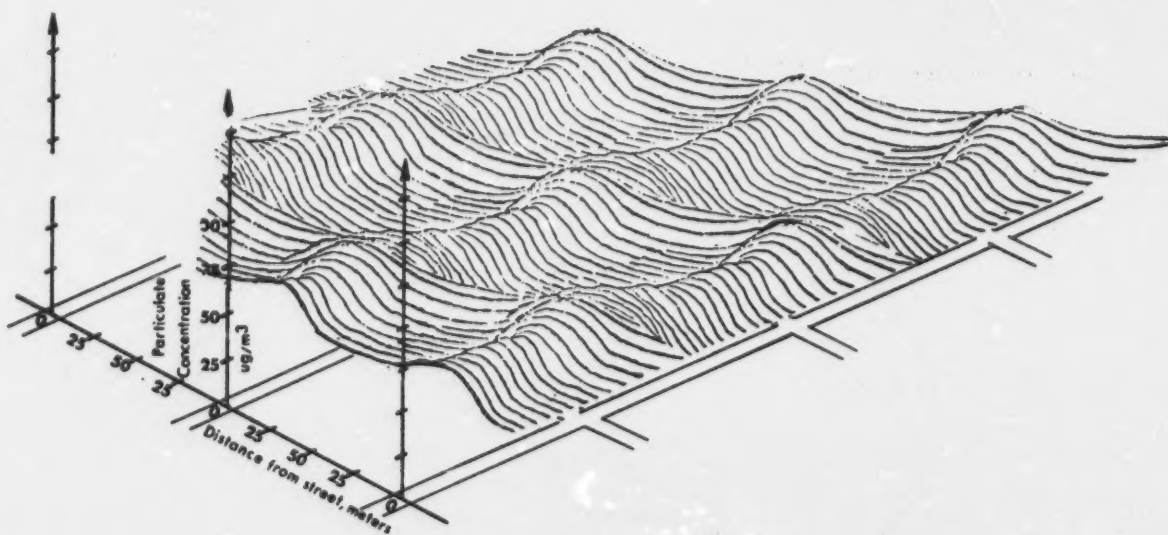
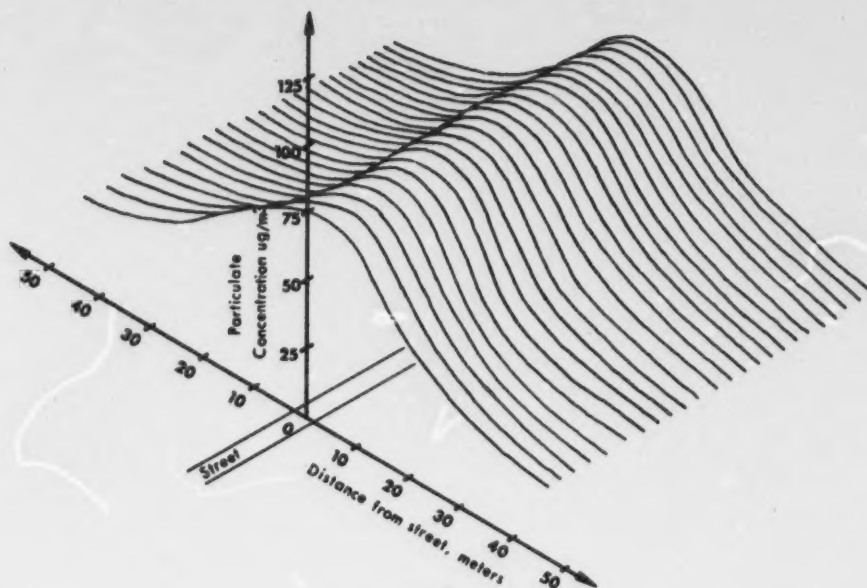


Figure A-1. Particulate concentration gradients near streets.

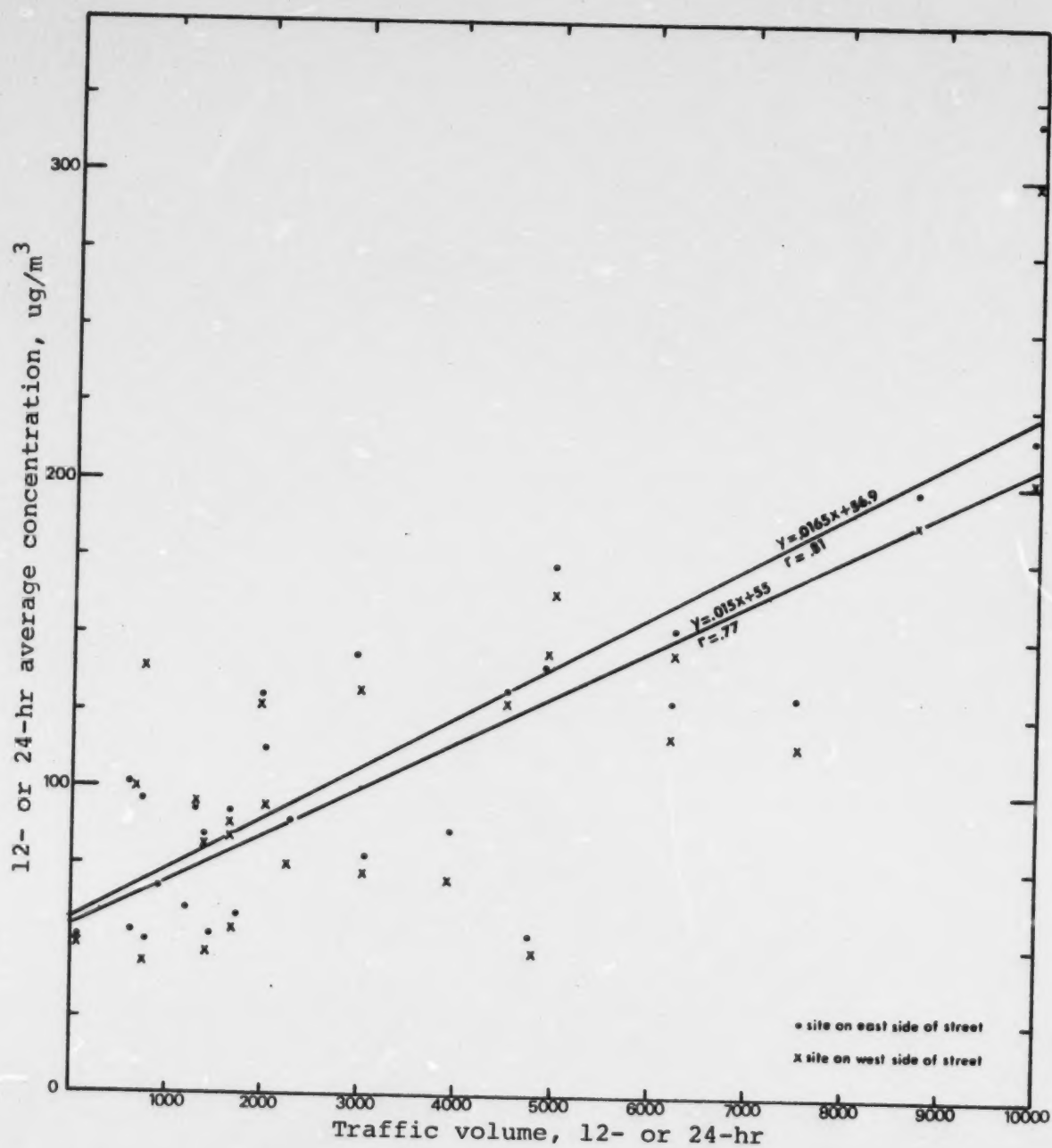


Figure A-2. Traffic volume versus concentration for McGee Street sites, Kansas City.

Table A-1. EFFECT OF TRAFFIC VOLUME ON CONCENTRATIONS

Location/ period	Av. traffic volume for period	Arith. av. particulate concentration, ^a ug/m ³	
		Ground level (5ft) sites	Elevated (20ft) sites
<u>McGee Street, Kansas City</u>			
Weekday	5360	140.4	129.6
Weekend	1560	92.2	81.4
8 a.m. to 8 p.m. (day)	3190	196.4	177.3
8 p.m. to 8 a.m. (night)	863	100.9	80.6
<u>Hamilton Ave., Cincinnati</u>			
Weekday	17792	70.6	63.7
Weekend	17325	66.6	60.8
8 a.m. to 8 p.m. (day)	12682	72.2	63.7
8 p.m. to 8 a.m. (night)	5110	59.8	56.7

^a All samplers are 35 ft back from edge of street.

point; each vehicle on McGee Street has a larger incremental effect on measured concentration than a vehicle on Hamilton Avenue. There are two probable explanations for this finding:

- ° Hamilton Avenue is the only arterial street in a primarily residential area while McGee Street is surrounded by other streets carrying comparable or greater traffic volumes (similar to the two examples in Figure A-1). The measured concentrations may be showing a relationship with traffic density in the area surrounding the sampling sites rather than with traffic volume on the nearest street.
- ° Average emission rates per vehicle may be considerably different on different streets, varying with such factors as type and condition of street pavement, traffic speed, or amount of material on the street surface (see below).

STREET SURFACE LOADING

The recent EPA-sponsored study to develop emission factors for reentrained dust from paved streets concluded that the emission rate is directly proportional to the weight of material on the street surface.¹⁵ This conclusion was based primarily on samples taken on a street with extremely high artificial surface loadings. No other previous investigations of the relationship between surface loadings and reentrained dust emissions were found, although studies of accumulation rates of material on streets indicate that the rate of material removal between rains or cleaning (assumed to be primarily by reentrainment) increases as the street loading increases.

In the project field studies, no consistent relationship was found between street surface loadings (either total or just the material in the traffic lanes) and particulate concentrations measured on the same day. Correlation between these two variables was not improved when the weight of material on the street subject to direct reentrainment

(less than 44 u size) was substituted for total street loading. Even when differences in traffic volumes during different sampling periods were accounted for by stepwise linear regression, reentrained dust emission rates and ambient concentrations near a street appeared to be independent of the amount of material on the street. Results of the linear regression analyses are summarized in Tables A-2 and A-3.

It should be noted that there is no standardized procedure for measuring the weight of material on street surfaces. In fact, one of the major conclusions of a recent American Public Works Association study of street cleaning was that a standard method is needed so that the efficiencies of commercial street cleaning equipment can be evaluated.⁶¹ The procedure used to measure street loadings in conjunction with the reentrained dust study was to vacuum a 100 ft length of the street from curb to curb with a large, gasoline-powered vacuum cleaner, then to transfer the collected sample with a household vacuum from the cloth bag to a small, disposable paper container. The procedure is described in detail in Appendix D. The collection efficiency of the sampling and transfer operations combined were checked and found to be approximately 85 percent, with much of this loss probably being fines passing through the cloth bag or released during sample transfer. However, surface loading values obtained by this method were substantially lower than those reported in a previous comprehensive study of street loadings that has been widely used as an information source on this subject.¹⁷

The problem of a satisfactory sampling procedure is compounded by the non-uniform occurrence of material along the streets. The 100 ft section of street sampled may not be representative of surface loading for a longer section of the street being studied, even though surface loadings are most commonly reported in units of lb/curb mi.

Table A-2. CORRELATIONS BETWEEN STREET LOADINGS AND
AMBIENT CONCENTRATIONS

Street	Street loading samples	No. of samples	Correlation (r) with	
			particulate concentrations	total street ldg wgt <44u
McGee	Traffic lanes	20	-0.218	-0.237
McGee	Total ^a	11	-0.100	-0.409
Hamilton ^b	Total	27	0.372	0.176
23rd Street	Traffic lanes	13	0.263	0.236
Brush Creek	Traffic lanes	20	0.120	0.192
Cleveland	Traffic lanes	9	-0.535	-0.700
31st Street	Traffic lanes	11	-0.007	-0.155

^a Curbs and traffic lanes.

^b Sampling location in Cincinnati. All other locations
are in Kansas City.

Table A-3. STEPWISE LINEAR REGRESSION ANALYSIS FOR
SHORT-TERM STUDIES

Dependent variable - downwind added concentration, $\mu\text{g}/\text{m}^3$

Independent variable	Correlation coefficient		
	Conc. @ 10m	Conc. @ 20m	Conc. @ 30m
<u>Single correlations</u>			
Traffic volume	.474	.468	.298
Traffic speed	-.262	-.343	-.325
Street loading	-.117	.119	.140
Wind speed	.405	.284	.289
<u>Stepwise cumulative</u>			
Traffic volume	.474	.468	b
Wind speed	.568	.561 ^a	b
Traffic speed	.595	.511 ^a	b
Street loading	no increase	.573	b

^a Traffic speed is the second variable used.

^b Data not meaningful because traffic speed ($r = -0.325$) was first variable used.

There are some possible, but untested, reasons other than the problems of measurement that could explain the lack of correlation between street loadings and particulate concentrations:

- ° Only a small portion of the material already on the street surface may be available for reentrainment due to its location in cracks, cementation to the surface, etc., while a much larger portion of freshly deposited material is subject to reentrainment. This would result in a short average residence time for most of the material.
- ° Reentrainment may be a function of surface loading up to some threshold loading above which the rate of reentrainment is sharply limited by another unknown factor.

Whatever the explanation, these new data indicate that the process of reentrainment from paved surfaces is complex. For example, reducing surface loadings by street cleaning may not proportionately reduce the air quality impact of reentrained dust.

WIND SPEED AND DIRECTION

According to the data in Table A-3, wind speed is directly rather than inversely related to the net (downwind minus upwind) vehicle-related concentration from streets. This means that the dust generating and transport effects of increased wind speed more than offset the diluting effect of the higher wind speed within the range of wind speeds encountered.

For one-hour periods with consistent wind directions, downwind samplers at 10 m from the edge of the road had average concentrations 82.1 percent higher than concentrations the same distance upwind. Over 24-hour periods in a relatively open area (Hamilton Avenue sites), the pole samplers which were downwind most of the day only averaged

13.6 percent higher than the upwind samplers because of the changing wind directions. Where samplers were located in a street canyon (McGee Street sites), channeling and localized wind flow during 24-hour periods tended to obscure the distinct upwind-downwind relationship as determined from wind directions measured at rooftop level. The pole samplers on the east side of the street were 9.5 percent higher than those on the west when they were downwind, but they also measured 6.7 percent higher concentrations when they were upwind according to the rooftop wind direction recorder. Data on upwind-downwind relationships are summarized in Table A-4.

SAMPLING HEIGHT

A well-defined reduction in particulate concentrations with increase in height was found at sampling sites near streets, as shown in Table A-5. At low levels (5 and 20 ft), the reduction in concentration with height was similar to that determined from more extensive vertical sampling studies performed in other cities at sites with general urban exposures.^{64,65} The vertical profile of concentrations up to at least 200 ft height from these previous studies appears to show an inverse power relationship of the form:

$$\chi = ah^{-b} \quad (\text{eq.1})$$

where χ = concentration at height h
 a and b = constants

between height and concentration, as shown in Figure A-3. An inverse power relationship has also been proposed for the vertical profile of particulate concentrations in dust storms.⁶⁶

Table A-4. UPWIND-DOWNWIND RELATIONSHIPS

	Short-term Study	Sites		Cincinnati	
		Kansas City East ^a	West	East	West
Days downwind	39	45	28	66	22
Av downwind conc, ug/m ³	153.0	123.7	112.3	71.6	69.2
Av upwind conc, ug/m ³	84.0	113.0	120.4	60.7	63.3
Av difference	69.0	10.7	-8.1	10.9	5.9
Difference, per- cent of upwind conc	82.1	9.5	-6.7	17.9	9.3
Std dev of difference	39.7	15.7	16.2	11.0	7.7

^a Side of street.

Table A-5. CONCENTRATION DEPENDENCE ON SAMPLER HEIGHT

Pollutant/Site	Av concentration, ug/m ³		Std dev of	% reduction
	At 5 ft	At 20 ft	Difference	from 5-20 ft
Suspended particulate				
KC east side	127.6	116.1	11.5	9.0
KC west side	117.4	109.0	8.4	7.2
Cinc east side	73.2	65.2	8.0	10.9
Cinc west side	66.4	60.9	5.5	8.3
Lead				
KC east side	1.90	1.63	0.27	14.2
KC west side	1.73	1.49	0.24	13.9

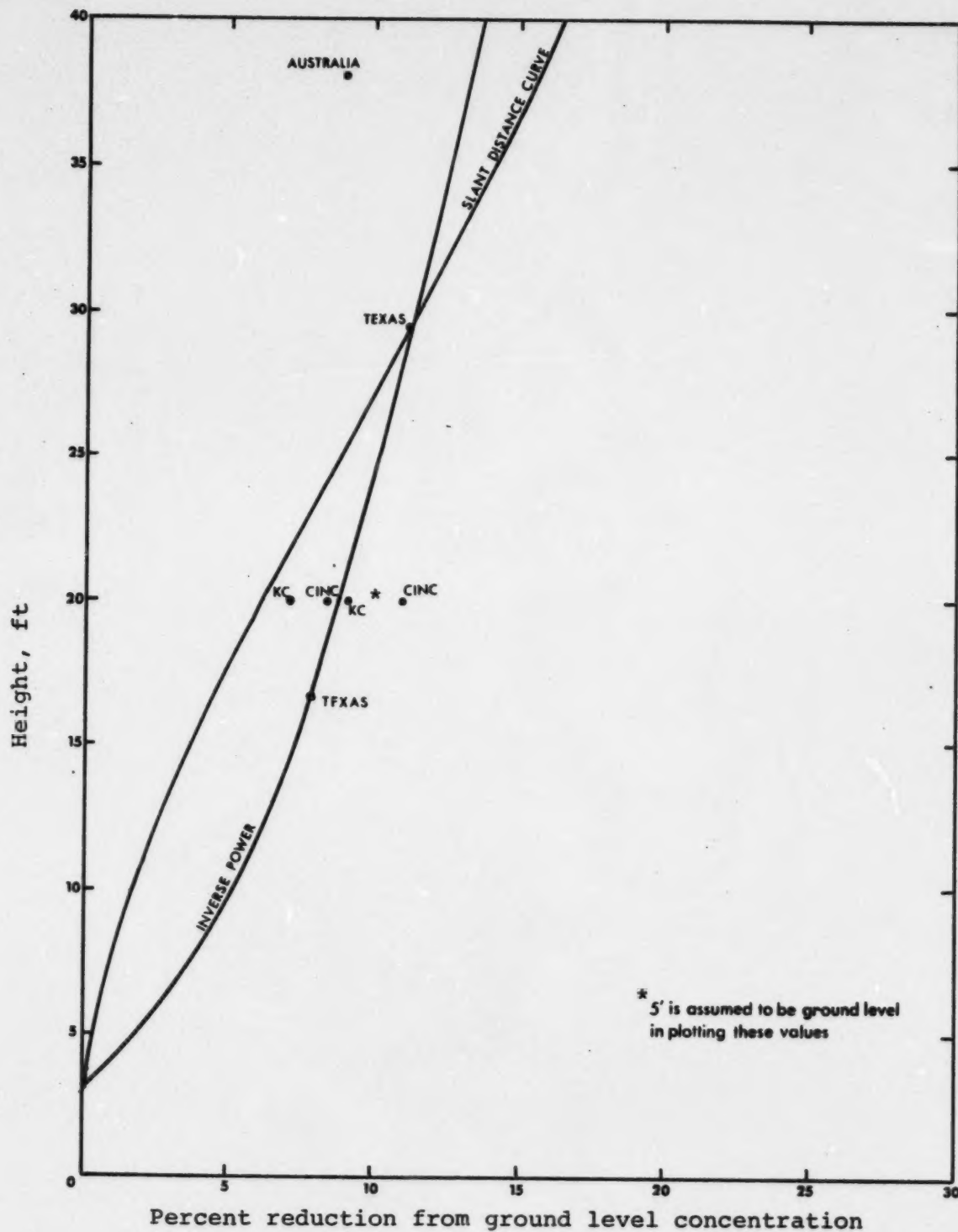


Figure A-3. Reduction in concentrations with increase in height.

The data points from the reentrained dust field studies also fit the "slant distance" curve proposed in the National Assessment of the Urban Particulate Problem reasonably well.⁵ This empirical curve was developed to describe the impact of nearby major streets on measured concentrations:

$$\chi = a + \frac{b \text{ (ADT)}}{\sqrt{h^2 + d^2}} \quad (\text{eq.2})$$

where χ = predicted concentration at sampling site

h = height of sampler

d = horizontal distance of sampler from nearest street

ADT = average daily traffic on street

a and b = constants

The above equation was used with values of $a = 45$, $b = 0.15$, ADT = 10,000, and $d = 35$ ft to plot the curve of concentration versus height that is also included in Figure A-3.

The reduction in lead concentrations with height (again at the 5 and 20 ft sampling heights) was greater than for total suspended particulate. Comparison of lead and total suspended particulate are discussed further in a following section.

EMISSION RATES

Vehicle-related emission rates were estimated from short-term (1 to 2 hour) high volume samples taken at distances of 10, 20, and 30 m from the downwind edge of a street and at 10 m upwind of the street. Only sampling periods during which the wind direction remained fairly consistent with the original upwind-downwind sampling configuration for more than 90 percent of the time were used in calculations. Also, data from four sampling periods were eliminated because of extreme wind speeds--average wind

speeds for two were less than 2.0 mph and for two others were greater than 16 mph.

The net downwind concentrations at each of the three distances for each sampling period were substituted into the Gaussian line source equation below with other appropriate input data to calculate the apparent line source emission strength.

$$\chi = \frac{2q}{\sin \phi \sqrt{2\pi} \sigma_z u} \quad (\text{eq.3})$$

where χ = plume centerline (ground level) concentration at a distance x downwind from the highway, g/m^3

q = line source strength, g/sec-m

ϕ = angle between wind direction and the line source

σ_z = the vertical standard deviation of plume concentration distribution at the downwind distance x , for the prevailing atmospheric stability and including an initial σ_z of 1.5 m, m

u = mean wind speed, m/sec

The calculated values of q were normalized to an emission rate per vehicle by dividing by the hourly traffic volume for each sampling period.

The net downwind concentrations and calculated emission rates per vehicle for 35 sampling periods are shown in Table A-6. The average emission rate for all this data is 3.7 g/veh-mi and the standard deviation is 3.3, both of which agree reasonably well with results of the EPA emission factor development study¹⁵ (average rate for particles less than 30 μ of 8.5 g/veh-mi , range for different land uses of 1.6 to 16 g/veh-mi) and a summary of resuspension studies¹⁶ which concluded that the resuspension rate for particles

Table A-6. CALCULATION OF VEHICLE-RELATED EMISSION
RATES FROM SHORT-TERM SAMPLING STUDIES

Study no.	Net downwind concentration, $\mu\text{g}/\text{m}^3$			Aver emission rate/vehicle, g/veh-mi		
	10m	20m	30m	10m	20m	30m
3	76.9	40.5	33.3	2.98	2.10	2.16
4	46.7	40.6	59.7	2.83	3.27	5.98
7	85.3	59.3	35.0	1.65	1.54	1.13
10	90.5	54.4	39.6	7.99	6.41	5.83
12	34.1	7.8	2.1	2.13	0.64	0.21
13	40.2	5.7	0	3.38	0.64	-
16	35.9	20.9	20.2	1.99	1.54	1.87
18	16.8	5.5	2.9	1.32	0.58	0.38
20	9.6	1.6	16.6	0.42	0.09	1.20
22	62.9	37.8	32.0	1.62	1.30	1.37
23	42.9	37.0	41.2	6.66	7.66	10.66
25	48.7	48.4	15.3	1.10	1.45	0.57
26	72.3	40.7	24.5	5.36	4.03	3.04
27	73.2	59.9	36.8	2.87	3.13	2.42
28	132.1	119.7	61.2	16.67	20.16	12.88
29	36.5	23.7	22.4	5.86	5.06	5.99
30	80.3	71.3	68.5	6.44	7.62	9.15
31	62.1	53.4	41.6	1.46	1.68	1.63
34	30.1	2.7	0	1.54	0.19	-
37	46.1	27.6	10.9	5.15	4.12	2.04
38	85.5	62.5	26.9	4.31	4.18	2.25
39	44.8	28.9	6.9	3.15	2.72	0.81
40	166.1	132.4	74.4	3.38	3.95	2.52
41	54.7	20.9	38.8	7.84	4.00	9.28
42	30.7	15.9	9.6	2.38	1.64	1.24
43	73.3	44.0	30.2	5.68	4.57	3.90
45	61.2	39.8	43.4	5.01	4.33	5.92
47	64.6	29.5	9.5	1.84	1.12	0.45
49	71.0	29.6	22.5	6.88	3.84	3.63
50	76.4	58.0	33.4	1.23	1.25	0.90
51	90.4	57.7	13.3	4.45	3.79	1.09
52	90.3	58.4	36.8	1.89	1.63	1.29
54	148.6	95.7	75.4	8.12	6.98	6.87
56	99.1	51.5	38.1	7.69	5.33	4.93
57	98.5	81.0	36.5	4.34	4.76	2.68
av.	67.9	44.7	30.3	4.21	3.63	3.26

less than 40 microns is in the range of 1 to 5 g/veh-mi. EPA's final recommended emission factor for reentrained dust will probably consider all three of these values.

It has been proposed, but not confirmed, that reentrained dust emission rates vary as a function of the land use surrounding a street.¹⁵ Data for the 35 sampling periods were obtained at four different sampling locations which are in areas of contrasting land uses, so the average emission rates for each location were compared to test the land use hypothesis. As shown in Table A-7, there are variations in average emission rates from different streets, but the variations are not as large as the proposed correction factors based on land use and do not indicate that commercial streets have lower emission rates per vehicle than residential streets. Therefore, until more specific data on the variables affecting reentrained dust emission rates become available, it is recommended that a single average emission rate for all streets be used rather than attempting to adjust rates on the basis of land use or street surface loadings.

FALLOUT

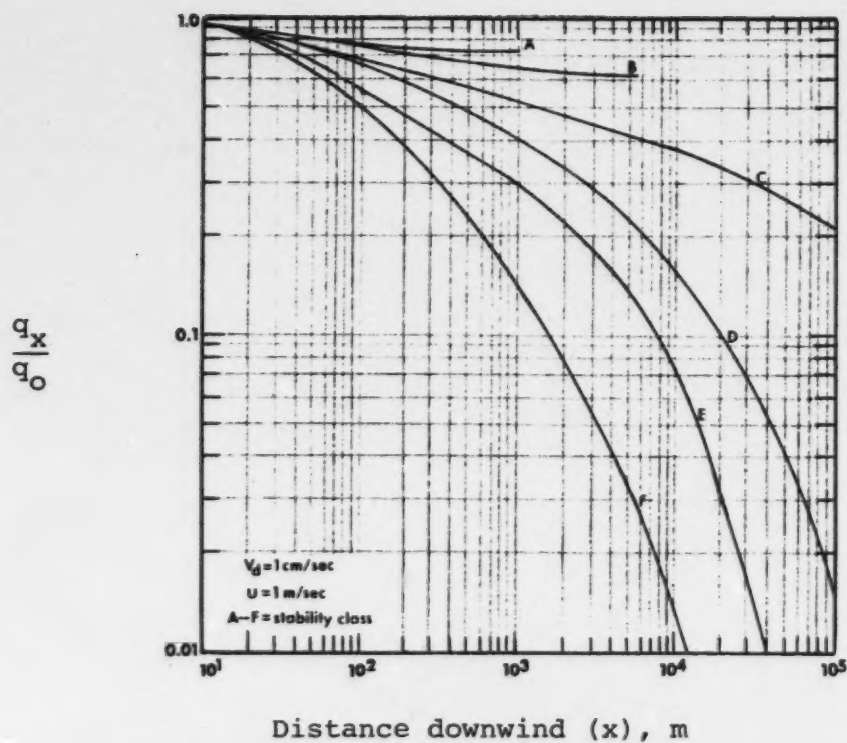
The data in Table A-6 show generally lower apparent emission rates with increased distance from the street. This reduction is attributed to deposition or fallout of heavier particles.

The deposition of small airborne particles has been investigated and shown to be a function of ground-level particulate concentration and settling velocity.⁶⁷ The rate of deposition is best described numerically in terms of a source depletion factor (q_x/q_0), the ratio between the apparent emission rate (q_x) at a distance x downwind and the initial emission rate (q_0). Depletion factors for different stability classes are presented graphically in Figure A-4.

Table A-7. EMISSION RATES IN AREAS WITH DIFFERENT LAND USES

Land use description	Short-term study site			
	1 Undeveloped, (no curbs on streets)	2 Park	3 Residential, some com- mercial	5 Extensive commercial and campus
No. of sampling periods	12	10	5	8
Av. emission rate, g/veh-mi				
@ 10m	5.32	3.92	2.78	3.84
@ 20m	4.70	2.61	2.60	3.94
@ 30m	4.96	2.53	1.56	3.89
MRI ^a emission factor (< 30u) based on land use, g/veh-mi	no factor	4.9	4.9	1.2

^a Source: Quantification of Dust Entrainment from Paved Roadways. Midwest Research Institute, Kansas City, Missouri. Prepared for U.S. Environmental Protection Agency. March 1977.



$$\left(\frac{q_x}{q_0}\right)_2 = \left(\frac{q_x}{q_0}\right)_1^{V_{d2}/u_2} \quad (\text{eq. 4})$$

Figure A-4. Source depletion factors by stability class for ground level sources.

Source: Meteorology and Atomic Energy. U.S. Atomic Energy Commission, Oak Ridge, Tennessee. 1968.

For wind speeds (u) greater than 1.0 m/sec or deposition velocities (V_d) greater than 1.0 cm/sec, the source depletion factor can be calculated as follows:

$$\left(\frac{q_x}{q_o}\right)_2 = \left(\frac{q_x}{q_o}\right)_1 V_{d2}/u_2 \quad (\text{eq. 4})$$

The deposition velocity (V_d) may be greater than the gravitational fall velocity (V_g) for the same size particles because it also includes such nongravitational removal mechanisms as surface impaction, electrostatic attraction, adsorption, and chemical interaction. For example, the average V_g for the reentrained dust samples should be 1.5 cm/sec (equivalent to a mass median diameter of about 15 microns and an average density of 2 g/cm³). However, the deposition velocity which matches the sampling data in Table A-6 best is 5 cm/sec. If this is assumed to be a representative deposition velocity for reentrained dust, then depletion of impact would be fairly rapid with distance away from the street. At one km downwind, the apparent emission rates would be only 11, 22, or 34 percent of the initial rates for B, C, or D stability.

The fallout of reentrained dust should be considered in any regional scale dispersion modeling for suspended particulate. Also, for microscale analyses which include the source depletion factor to account for fallout, the initial emission rate (q_o) corresponding to the average emission rate of 3.7 g/veh-mi is 4.9 g/veh-mi. Short-term (up to 1 hr) impact downwind of a street can then be calculated with the line source equation which has the depletion factor incorporated:

$$\chi = \frac{1.7 \times 10^{-6} \left(\frac{q_x}{q_o} \right) V}{\sin \phi \sqrt{2\pi} \sigma_z u} \quad (\text{eq. 5})$$

where $\frac{q_x}{q_o}$ = source depletion factor determined from Figure A-4 and equation 4

V = traffic volume on street, veh/hr

and other variables are as defined in equation 3. Values of σ_z can be estimated from the equation⁶⁸

$$\sigma_z (x) = ax^b + \sigma_o \quad (\text{eq. 6})$$

where x = distance downwind, m

$\sigma_o = 1.5 \text{ m}$

a = 0.1120 for C stability,
0.0856 for D stability

b = 0.910 for C stability,
0.865 for D stability

PARTICLE SIZE

Several of the high volume samples from the project field studies were examined microscopically to determine the particle size distribution of particulate matter collected near streets and its percent composition by particle origin. Of the 66 cellulose acetate filters exposed during the studies, 38 had light enough loadings that the collected material could be subjected to direct microscopic examination at 100 power. The microscope was equipped with a polarizer and a calibrated Porton reticle. The four distinct particle origins which could be identified microscopically were: combustion product, mineral matter, biological debris, and tire tread.

Percent distribution for each particle size range was calculated by number of particles and by weight. The

percent by number was determined directly from the counts for each particle size range. The percent by weight was determined by multiplying the number of particles by the average particle volume and the weighted average density (based on composition). Assumed densities were 1.0 g/cm³ for combustion products, 2.6 for mineral matter, 1.1 for tire tread, and 1.0 for biological debris.

The size distributions and compositions of the 38 suspended particulate samples are presented in Tables A-8 and A-9, respectively.

The particles were observed to be quite large--a mass median diameter of 15 u and approximately 22 percent by weight greater than 30 u diameter. The samples were relatively uniform in their size distributions, even though they were taken at several different locations at various distances from major streets. Most studies of urban particulate have indicated mass median particle sizes of less than 5 u. The large particle size of the reentrained dust supports the high observed fallout rates described in the previous section.

Most of the samples also displayed a strong bimodal distribution, with a large percentage of the material being less than 3 u in diameter and another large percentage in the 15 to 30 u range. The small particulate (less than 3 u) was identified as mainly combustion products, while most of the large material was of mineral origin.

Combustion particles generally constituted more than 80 percent of the number of particles on the filters but, because they were much smaller than the other particles, accounted for an average of 40 percent of the weight of suspended particulate. Mineral matter averaged almost 59 percent by weight of the material collected; biological debris contributed 1.4 percent average; and tire tread particles were usually a negligible component of the samples.

Table A-8. PARTICLE SIZE DISTRIBUTION OF
HIGH VOLUME SAMPLES

Location		Date	Percent by weight by particle size range (microns)					
			<3.8	3.8-7.5	7.5-15.0	15.0-30.1	30.1-42.6	>42.6
McGee St	A1	10-26	15.3	4.1	8.6	22.5	10.3	39.2
	A3	10-26	21.0	5.7	13.4	27.6	21.8	10.5
	A3	11-23	14.1	2.7	9.9	38.1	17.6	17.6
Locust St	A5	10-26	36.8	4.5	12.0	21.8	19.1	5.8
	A5	11-23	22.2	5.5	10.6	31.9	11.4	18.4
	A6	10-05	46.3	4.3	11.5	24.7	11.9	1.3
	A6	10-26	34.6	11.6	18.2	34.4	0.5	0.7
	A6	11-23	28.3	5.1	12.8	31.8	18.4	3.6
Oak St	A8	10-26	20.6	4.5	11.5	20.7	17.5	24.9
	A8	11-23	13.4	2.5	9.7	36.8	26.6	10.9
43rd St	B9	10-07	34.0	5.4	19.5	39.7	1.2	0.2
	B9	10-27	21.0	2.6	11.8	35.9	15.1	13.6
	B9	11-24	22.4	4.7	11.9	43.7	14.4	2.9
	B10	10-07	45.8	6.1	19.5	28.6	0	0
	B10	10-27	20.2	3.5	13.3	35.6	20.5	6.9
	B11	10-07	28.4	4.3	17.1	33.9	12.9	3.4
	B11	10-27	12.6	1.8	7.4	23.2	21.1	27.9
	B11	11-24	21.2	3.4	12.3	34.2	21.2	7.7
	B12	10-07	38.0	5.9	16.1	36.1	1.7	2.2
	B12	10-27	15.5	3.4	13.5	39.2	16.6	11.8
50th St	C13	10-07	37.4	3.7	11.8	34.7	15.5	7.4
	C13	10-27	35.2	3.5	14.8	28.5	11.8	6.2
	C13	11-24	19.7	3.7	11.2	44.4	19.5	7.5
53rd St	C14	10-07	31.4	3.4	12.9	38.2	9.7	4.4
	C14	10-27	31.5	4.2	15.7	30.0	16.1	2.5
	C14	11-24	22.7	5.6	12.2	44.7	7.4	7.4
Stadium Dr	D15	10-07	24.2	4.2	11.6	25.5	29.9	4.6
	D15	10-27	29.8	12.2	22.2	22.3	0.9	12.6
Hamilton Av	2B	11-09	39.3	9.7	11.8	19.2	19.0	0
	2T	11-09	34.7	10.5	13.2	20.8	20.4	0.4
	2T	12-07	17.9	2.5	6.9	21.8	15.7	35.2
	3B	11-09	29.9	5.4	14.1	23.3	27.3	0
	3B	12-07	38.9	6.9	13.0	15.7	2.9	22.6
	3T	11-09	58.7	10.9	16.4	14.0	0	0
	3T	12-07	26.6	6.2	13.3	25.1	3.0	25.8
Marlowe Av	4	11-09	46.7	8.1	17.0	28.2	0	0
	4	12-07	79.0	6.5	9.8	4.9	0.8	0
Llanfair Av	5	11-09	43.9	10.2	14.6	21.9	8.4	1.0
Mean			30.5	5.5	13.2	29.0	12.8	9.1
Std dev			13.5	2.7	3.3	9.0	8.6	10.4

Table A-9. SUSPECTED ORIGIN OF PARTICULATE MATTER IN
HIGH VOLUME SAMPLES

		Origin of particulate matter, % by wt				
Location		Date	Combustion products	Mineral	Biological matter	Tire tread
McGee St	A1	10-26	38.0	60.1	1.9	neg
	A3	10-26	38.4	60.4	1.2	neg
	A3	11-23	39.3	59.3	1.3	0.1
Locust St	A5	10-26	48.9	49.3	1.7	0.1
	A5	11-23	45.4	52.1	2.4	0.1
	A6	10-05	58.2	38.7	3.1	neg
	A6	10-26	50.3	48.1	1.6	neg
	A6	11-23	41.9	53.0	5.1	neg
Oak St	A8	10-26	37.7	61.2	1.1	neg
	A8	11-23	30.8	67.5	1.6	0.1
43rd St	B9	10-07	32.9	66.0	1.1	neg
	B9	10-27	35.4	63.7	0.9	neg
	B9	11-24	22.8	76.3	0.9	neg
	B10	10-07	45.4	54.6	neg	neg
	B10	10-27	35.2	61.8	3.0	neg
	B11	10-07	35.5	63.6	0.9	neg
	B11	10-27	19.7	79.5	0.8	neg
	B11	11-24	33.6	64.5	1.7	0.2
	B12	10-07	37.2	61.6	1.2	neg
	B12	10-27	25.6	73.7	0.7	neg
50th St	C13	10-07	28.3	70.7	0.9	0.1
	C13	10-27	66.7	30.1	3.2	neg
	C13	11-24	15.6	83.7	0.6	0.1
53rd St	C14	10-07	43.9	54.4	1.7	neg
	C14	10-27	61.8	33.6	4.6	neg
	C14	11-24	22.5	76.5	1.0	neg
Stadium Dr	D15	10-07	29.9	69.4	0.7	neg
	D15	10-27	36.6	62.8	0.5	0.1
Hamilton Av	2B	11-09	38.3	61.6	0.1	neg
	2T	11-09	30.4	69.0	0.6	neg
	2T	12-07	35.5	63.7	0.8	neg
	3B	11-09	29.1	70.9	neg	neg
	3B	12-07	55.0	44.0	1.0	neg
	3T	11-09	44.5	55.3	0.2	neg
	3T	12-07	64.9	33.6	1.4	0.1
Marlowe Av	4	11-09	38.1	61.8	0.1	neg
	4	12-07	82.8	16.1	1.1	neg
Llanfair St	5	11-09	40.4	58.2	1.4	neg
Mean			39.9	58.7	1.4	<0.1
Std dev			13.8	14.3	1.1	<0.1

Combustion products were a surprisingly large percentage of the particulate at all sampling locations, indicating that exhaust emissions may be higher than previously suspected. The ratio of exhaust emissions (based on the published emission rate of 0.34 g/veh-mi) to total vehicle-related emissions (4.9 g/veh-mi) would indicate an average contribution closer to 10 percent combustion products rather than the reported 40 percent in the ambient samples.⁶² Of course, some of the measured concentrations are due to sources other than vehicle-related emissions and a high percentage of this particulate matter could be combustion products.

LEAD

The project field studies provided several comprehensive sets of data on ambient lead concentrations near streets. Average lead concentrations at all sampling sites downwind of streets were in the range of 0.7 to 2.0 $\mu\text{g}/\text{m}^3$. The highest recorded 24-hour concentrations out of 269 samples were 4.6 and 4.2 $\mu\text{g}/\text{m}^3$. The highest one-hour concentrations out of 239 samples (short-term studies) were 5.8 and 3.9 $\mu\text{g}/\text{m}^3$.

Lead concentrations measured at 20 ft height were almost always lower than concentrations during the same time period at 5 ft, but the percent reduction was highly variable. This reduction in lead concentration from 5 ft to 20 ft averaged 11.8 to 35.7 percent at four different locations. The reductions in lead concentration with height were greater than for total suspended particulate; no explanation was found for this.

Correlations between measured lead concentrations and traffic volume during the sampling period were moderate at sampling sites in all of the studies where traffic counts were available--in the range of 0.3 to 0.5. Correlations

between lead concentration and traffic volume were not quite as high as correlations between suspended particulate concentration and traffic volume. However, traffic volume appears to be the single variable which most strongly affected ambient lead concentrations at the sampling sites near streets.

An average lead emission rate of 0.069 g/veh-mi was calculated using the same method as that for estimating the vehicle-related particulate emission rate--a line source dispersion equation, equation 3, and short-term downwind ambient lead concentrations. A value of 0.076 g/veh-mi was determined based on the weighted average lead content of gasoline, assuming that 70 percent of the lead in the gasoline is exhausted from the tailpipe.⁶⁹ The calculated emission rate was quite uniform at the different locations where the short-term sampling was conducted, but the standard deviation of the calculated emission rate from all the sampling periods was 0.047, almost as high as the average emission rate.

The apparent emission rates calculated at distances of 10 m, 20 m, and 30 m were approximately the same, indicating that lead was not falling out of the plume within this distance from the street (in contrast with the deposition of total suspended particulate described on page A-18).

Lead averaged one to two percent of the suspended particulate at all sampler locations except the sites which were always upwind of streets. This consistent lead fraction was attributed to the similar exposures of the samplers, 10 m to 30 m back from the street. Very few individual samples had lead less than 0.2 percent of the total particulate and none were as high as 5.0 percent. Correlations between lead concentration and suspended particulate concentration at individual sampling sites were in the range

of 0.2 to 0.6, so the relationship between the two pollutants was not nearly as strong as indicated by the narrow range of average lead percentages.

The data for the above analyses of lead concentrations and more detailed discussion of the analyses can be found in a companion report to this document.⁷⁰

MATERIAL ON STREET SURFACES

This Appendix describes the derivation of the values reported in Chapter 2 for deposition and removal rates of individual processes. The underlying premise for this approach to the investigation of material on street surfaces is that a mass balance of total deposition and total removal rates can be used as a check on the estimated values.

Published information was relied upon to identify the processes by which materials enter and leave the street surface and to estimate the rate of flow associated with each process. Extensive chemical and microscopic analysis of street loading samples was not used to determine the origin of the sample components because this procedure could easily have consumed more resources than the primary effort, the testing of measures to reduce reentrainment.

The random nature of deposition and removal mechanisms and their great geographical variations limit the accuracy that can be achieved in estimating average rates. Replicate sampling on adjacent roadway sections reveals a standard deviation of about 25 percent just for total weights.²² Contributions by individual deposition processes would be expected to vary by wider margins on adjacent roadway sections and by orders of magnitude on streets in different land use areas.

CHARACTERISTICS OF MATERIAL ON STREETS

Some of the pure substances that have been found on street surfaces are:²²

- Gasoline
- Lubricating grease
- Motor oil
- Transmission fluid
- Antifreeze
- Undercoating
- Asphalt pavement
- Concrete
- Rubber
- Diesel fuel
- Brake linings
- Brake fluid
- Cigarettes
- Salt
- Cinders
- Area soil

The total weight of material is normally more than 95 percent inorganic and has a bulk density of about 1.6 g/cm^3 . Most of the material on street surfaces is too large to become directly airborne, according to published average particle size data:¹⁷

<u>Particle size range, u</u>	<u>Percent by weight</u>
>2000 ^a	24.4
840-2000	7.6
246- 840	24.6
104- 246	27.8
43- 104	9.7
< 43	5.9

The surface material is not distributed uniformly across the streets, as shown by the data in Table B-1.

^a Particles larger than $1/4$ " are removed from samples before weighing.

Table B-1. DISTRIBUTION OF SURFACE MATERIAL
ACROSS A TYPICAL STREET

Street location, distance from curb	Normal weight of material, % of total	Weight of material just after sweeping, % of total
0- 6 in.	78	45
6-12 in.	10	35
12-40 in.	9	13
40-96 in.	1	6
96 to center line	2	1

Source: Sartor, J. D. and G. B. Boyd. Water Pollution
Aspects of Street Surface Contaminants. U.S. Environ-
mental Protection Agency, Washington, D.C. Publication
Number EPA-R2-72-081. November 1972.

Almost all the dirt and debris collects within a foot of the curb, presumably due to air currents and direct displacement by passing vehicles.

Several street loading measurements were made during the reentrained dust field studies. These are summarized in Table B-2. With the exception of samples taken on McGee Street, at least 70 percent of the material on streets was concentrated in the 2 ft wide curb sections (average 86.5 percent). However, the percent of material less than 44 μ in size was found to average almost twice that previously reported in the literature.

The total street loadings for these recent measurements were also significantly lower than those reported in two other studies which involved extensive street sampling:

Study	No. samples	Street loading, lb/curb-mi			
		Mean	Median	Std. dev.	Range
PEDCo	129	150	80	120	9- 500
Shaheen ²²	127	320	180	480	8- 3400
Sartor and Boyd ¹⁷	n.a. (>72)	1500	n.a.	1200	31-12000

The lower measured loadings could be due to differences in the sampling methods used or in the types of streets tested. PEDCo's sampling methodology was similar to those for the other two studies except that streets were not flushed after they were broomed and vacuumed. However, the flushing fraction of samples in the other two studies contained only about four percent of the solids by weight. Some of the streets sampled to obtain data for this document were considered to be fairly "dirty" and were located in warehousing and industrial land use areas.

Table B-2. SUMMARY OF STREET LOADING SAMPLE DATA

Location	No. of samples	Avg. particle size dist., %			Avg. sample wt, lb/curb-mi	Curb Traffic lanes	Pct. in traf. lanes
		<44u	44-106u	106-84lu			
<u>Kansas City</u>							
McGee Street							
-A location	11	8.3	18.5	64.5	139	126	47.6
-B location	11	6.8	18.7	64.0	137	208	60.3
Westwood	9	9.8	25.8	49.8	40	6	12.1
Roeland Park	6	15.4	14.4	49.5	69	33	32.2
School							
Leeds	6	11.0	12.6	63.3	196	49	20.0
23rd Street	14	12.6	11.7	51.7	34	14	28.9
Brush Creek	19	10.5	15.5	50.2	32	6	15.6
Cleveland Ave.	11	12.8	12.4	55.4	111	13	10.4
Gillham	5	13.4	15.0	59.0	268	10	3.5
31st Street	10	9.0	20.9	57.4	322	13	3.8
<u>Cincinnati</u>							
Hamilton Ave.							
-A location	14	5.7	15.1	51.6		81 ^a	5.8
-B location	13	5.0	15.8	52.2		113 ^a	3.1

^a Combined curb and traffic sample.

It should be pointed out that the PEDCo measurements and Shaheen measurements are in closer agreement than the Shaheen/Sartor and Boyd values, although the latter data set has been most widely cited in related work. These differences in average street loadings reported in the different studies are important because much of the data on deposition and removal rates compiled from the literature are based on these values and are therefore higher than would be consistent with the street loading data in Table B-2.

DEPOSITION PROCESSES

Most deposition processes are linear with time, or deposit material at a fairly constant rate. Many of the processes are closely related to traffic volume, while others are dependent on immediately adjacent land use. "Typical" deposition rates for nine processes identified in the literature as significant contributors to street surface loadings are presented in Table B-3. The assumption has been made that the typical street is four-lane, 50 ft wide, and has an average daily traffic volume of 10,000 vehicles. The relative importance of vehicle-related deposition processes would increase on more highly traveled streets and decrease on streets with less traffic.

The term "curb-mi" for street loadings indicates the area bounded by the two curbs for a distance of one mile. The same unit (curb-mi), when used in reference to street cleaning, means a distance of one mile along one curb. Since there are two curb-mi to be cleaned in the length of street that constitutes one curb-mi for purposes of defining street surface loadings, the term is obviously quite confusing. In this chapter, it always has the first of the two definitions.

The reader is cautioned again about accuracy of the estimates for deposition and removal processes. The values

Table B-3. DEPOSITION PROCESSES

Source	Constituents	Typical deposition rate, lb/curb-mi/day	Range, lb/curb-mi/day
1. Mud and dirt carryout	Soil from construction sites, unpaved parking areas, etc.	100	Extreme
2. Litter	Cans, bottles, broken glass, cigarette butts, plastic, other debris	40	Extreme
3. Biological debris	Leaves, grass clippings, sticks, animal droppings, insect parts, etc.	20	Extreme
4. Ice control compounds	Sand, salt, cinders, calcium chloride	20	0-60
5. Dustfall	Atmospheric fallout	10	2-25
6. Pavement wear and decomposition	Asphalt, cement, aggregate, expansion joint compounds and fillers	10	5-150
7. Vehicle-related			
-Tire wear	Rubber	10	6-50
-Brake and engine component wear	Metals, lubricants, brake and clutch linings	5	2-25
-Settleable exhaust	Combustion products, fuel additives	2	1-10
8. Spills	Sand, dirt, chemicals	No data; est <2	
9. Erosion (runoff and blowing) from adjacent areas	Soil	20	Extreme
Total		240	

in Table B-3 are only order-of-magnitude estimates and should not be considered representative of deposition on a particular street. There are probably no streets that have the exact mix of contributions as that calculated based on typical rates for the individual processes.

Mud and dirt carryout, or tracking, appears to be the largest source of material on streets. This finding agrees with those from two other recent studies, Quantification of Dust Entrainment from Paved Roadways and Road Dust as Related to Pavement Polishing (neither of these two studies provided data to generate the estimate for the deposition rate from mud and dirt carryout).^{15,71} The amount of material deposited on a street by vehicular carryout on tires or undercarriages is obviously subject to wide variations depending on proximity to unpaved areas and the traffic across these areas.

The estimate of 100 lb/curb-mi/day was obtained by averaging the results of two different approaches: (1) calculating the difference between reported accumulation rates on wet and dry days²² and (2) determining the amount of material on vehicle tires and undercarriages which is subject to easy removal (0.13 lb/veh). The former approach indicated an excess accumulation rate of 44 lb/curb-mi/day, which did not consider dirt carryout contributions on dry days, and the latter approach yielded a rate of 163 lb/curb-mi/day for a traffic volume of 10,000 veh/day and an average trip length of eight miles.

Two additional large sources of material on streets are litter and biological debris. However, litter and biological debris are not major concerns in the dynamics of street loadings from an air pollution standpoint because these materials are not usually ground to the size where they could become airborne and they are efficiently removed by the other mechanisms. In fact, some analyses of street

surface material have excluded full consideration of these categories by limiting the size of materials included in the surface loading to less than 1/4 in.

The weight of litter on streets and its accumulation rate were measured separately from total street loadings in one study.²² The average deposition rate was 45 lb/curb-mi/day, but most of the streets sampled had very high traffic volumes. Adjusted to traffic volumes of 10,000 veh/day, the average rate was 26 lb/curb-mi/day. No data were found on the weight of biological debris in street loading samples, although some items in this category might be considered litter in segregating samples.

The application of ice control compounds to streets has the greatest geographical variation in deposition rates of all the processes. The estimate in Table B-3 is based on 10 applications per winter of 800 lb/curb-mi each, which is representative of a moderate winter climate. Sand or salt added to streets for ice control has more effect on street loadings than indicated by its relative contribution to typical deposition rates because it is all concentrated within a few months during which it frequently causes a doubling of average street loadings. Also, there is normally no street cleaning to remove the sand or salt during the winter. This deposition process is not a factor in southern climates.

Dustfall contributions to street loadings are based on the assumption that fallout rates are the same on streets as they are at the locations where dustfall measurements are taken. The deposition rate of 10 lb/curb-mi/day is equivalent to a dustfall rate of 16 ton/sq mi/month. The normal range of dustfall rates in urban areas is 9 to 40 ton/sq mi/month.^{5,6} Some dustfall measurements taken along road cross sections have indicated much higher dustfall rates on the road.⁷² However, this observation is attributed to the

trapping of resuspended material in the dustfall container and therefore does not represent new material entering the street deposition/removal system.

Pavement wear and erosion of areas adjacent to the street are two categories for which very little data on deposition rates could be obtained. Most available data indicate that neither process is consistently a major contributor. Calculations based on pavement wear (or polishing) rates show only about 10 lb/curb-mi/day loss,⁷³ but some microscopic examinations of loose surface material have shown pavement decomposition products to be almost half of the sampled material.^{3,73} There are two possible reasons why microscopic examination might yield higher than actual contributions from pavement wear: the sampling procedure may abrade the pavement and break loose aggregate particles that are included in the samples (this has been documented by resampling the same pavement area immediately);²² or mineral matter (calcite and quartz) tracked or blown onto the road may be mistaken for aggregate from the pavement by the microscopist.

The most information is available for material deposition processes directly related to vehicle operation--tire wear, brake and engine component wear, and the settleable portion of particulate exhaust emissions. Several studies of tire wear have all shown the same magnitude of 0.2 to 0.8 g/veh-mi, and most agree that about 90 percent of the tread loss is deposited on the surface or is initially in the settleable size range.^{62,74-78} Estimates of deposition from brake and engine wear were obtained from chemical analysis of street loading samples and from material balance of expendables.^{22,78} They show that these sources contribute an average of about half that of tire wear, or 5 lb/curb-mi/day for a daily traffic volume of 10,000 vehicles. Chemical analysis for engine exhaust products which settle

to the street surface indicate that deposition accounts for only about 25 percent of the emissions, with the rest remaining airborne. In particular, most of the lead emitted is of small particle size and remains suspended.

REMOVAL PROCESSES

Unlike the deposition processes, which occur at a linear rate with time, most removal processes are intermittent and primarily a function of the amount of material on the street at the time they occur. In other words, they operate with a fairly constant efficiency in removing material from the streets. An apparent exception to this is removal by reentrainment; according to data presented in Appendix A, reentrainment rates are independent of street loadings.

The major processes which remove material from streets are listed in Table B-4, along with estimates of typical amounts of material removed by each and the assumptions used in making these estimates.

Reentrainment is shown to be the largest removal process. The rate of 100 lb/curb-mi/day was estimated from a net emission rate of 4.5 g/veh-mi (total rate of 4.9 g/veh-mi minus direct emissions of about 0.4 g/veh-mi) and a traffic volume of 10,000 vehicles per day. Since this reentrainment rate agrees well with those obtained in other studies and represents the mass of material that definitely is emitted from the street, it is probably more accurate than the estimates of the other removal rates. The supply of material in the particle size range that can remain airborne must be continually replenished by the mechanical fracture of larger particles on the street surface.

A process closely associated with reentrainment is the displacement of material from streets to just beyond the curb, either by direct propulsion from the vehicles' tires, by splashing (when the pavement is wet), or from air turbulence

Table B-4. REMOVAL PROCESSES

Process	Typical removal rate, lb/curb-mi/day	Assumptions incorporated
Reentrainment	100	For 10,000 ADT; net removal rate = 4.5 g/VMT
Displacement	40	Estimated from dustfall rate just beyond curb
Wind erosion	20	Force of same magnitude as reentrainment, but only operative 20% of time
Rainfall runoff	50	Removal efficiencies of 50% for rain of 0.1-0.5. and 90% for rain of >0.5 in.
Sweeping	35	Average efficiency of removal = 50%; weekly clning

created by the vehicles. The displaced particles are too large to remain airborne. One study showed that street loadings were increased along sections of a street where barriers at the curb prevented material from leaving the street.²² Additional evidence of the magnitude of this process is provided by the rapid soiling of snow beside streets; a strip of material up to one meter wide is deposited just off the curb and is highly visible on white snow. The rate of removal due to displacement was estimated from dustfall measurements taken right at curbside.

Removal of material by wind erosion is difficult to distinguish from reentrainment because the material leaves the street as particulate air pollution in both cases. Also, the high wind speeds associated with wind erosion augment reentrainment rates by keeping a greater percentage of the reentrained material suspended. Wind erosion removes material in the absence of vehicular traffic at instantaneous wind speeds greater than about 12 mph, which occur less than 20 percent of the time in most parts of the country.⁷⁹ This removal process is important near curbs, where it lifts away material that may be outside the range of the reentrainment and displacement processes.

Available information on wind erosion rates are all for surface areas which are entirely covered with material subject to erosion, such as plowed fields. These values cannot be applied directly to street surfaces because erodible material is found on only a small portion of the surface area. One report estimated that wind erosion produced 35 percent as much impact as vehicle-induced reentrainment on regional network samplers in Chicago, but this included wind erosion over the entire urban area.⁶

Rainfall removes material by flushing it from the crown toward the gutter and then along the gutter to a catch basin. Some of the material is dissolved, but most is

carried in quasi-suspension. This removal mechanism has been studied in great detail. It was found that the most important factor in determining amount of removal was rainfall intensity--an intensity of more than 0.5 in./hr for a period of 30 min will remove 90 percent of the surface loading.¹⁷ A rain sufficient to wet the street completely and produce flow in the gutter will generally remove about 50 percent of the loading.

If it is assumed that any rain of more than 0.5 in. total removes 90 percent of the material present and any rain of 0.1-0.5 in. removes 50 percent of the material, climatological records for an area can be used to estimate the number of cleaning occurrences per year. With the additional assumption of a street loading at the time of the rains, the total annual removal per curb-mi by rainfall can be calculated directly and converted to an average daily removal rate. The surface loading on days when rain occurs would be greater than the average loading because these days are at the end of accumulation periods. Depending on which set of street loadings from page B-4 is used, the surface loading at the time of rain would range from 300 to possibly 1500 lb/curb-mi. If a loading of 500 lb/curb-mi is assumed for a hypothetical area with 18 days per year of greater than 0.5 in. rain and 40 days with 0.1-0.5 in. rain, the total annual removal would be:

$$(500 \text{ lb/curb-mi})(0.9)(18) = 8100$$

$$(500 \text{ lb/curb-mi})(0.5)(40) = \underline{10000}$$

$$18100 \text{ lb/curb-mi/yr}$$

$$(50 \text{ lb/curb-mi/day})$$

In areas with much rainfall or where streets have higher surface loadings than estimated above, removal from rainfall flushing could be comparable to that from reentrainment.

Street sweeping has an average removal efficiency of 50 percent.^{22,80} Like rainfall, sweeping occurs at times with greater than average street loadings (at the end of accumulation periods). If a 500 lb/curb-mi loading prior to sweeping and weekly sweeping are assumed, the removal rate would be 250 lb/curb-mi every seven days, or 35 lb/curb-mi/day. If street cleaning were done daily, the loadings prior to cleaning would not be 500 lb/curb-mi, but instead approximately 200 lb/curb-mi based on the deposition and removal rates presented in Tables B-3 and B-4. Thus, the daily removal rate would be 100 lb/curb-mi/day, or about three times the removal rate of weekly cleaning.

Another approach was also used to estimate removal rates by street cleaning. Reported sweeper pickup rates for four cities averaged about 0.25 ton/curb-mi (one side of street), or 1000 lb/curb-mi (gutter to gutter).¹⁷ These values are much higher than those discussed above and tend to confirm the higher street loadings estimated by Sartor and Boyd. Assuming weekly cleaning, the removal rates from street sweeping in the four cities would be 140 lb/curb-mi/day, even higher than the rate of removal by reentrainment. However, use of the latter estimated removal rate (140 lb/curb-mi/day) would cause total removal rates to be much higher than identified deposition rates. Therefore, the value of 35 lb/curb-mi/day has been used in Table B-4.

Based on this crude mass balance for materials entering and leaving the street surface, it appears that almost half the material may leave the street as particulate air pollution. In addition, motor vehicles emit some particulate matter in the engine exhaust which adds to the vehicular impact on air quality but which does not enter into the reentrainment process.

ACCUMULATION RATES

Material deposition on streets is fairly constant with time and independent of the surface loading. However, the accumulation rate is not linear, but approaches zero as the rate of removal increases with the loading. It has been found that the street loading reaches an equilibrium level, at which the deposition and continuous removal processes are about the same, within a fairly short period of time--three to five days after a rain or street cleaning reduces the loading.²² If the net accumulation rate did not decrease as the loading increased, uncleaned streets would eventually become impassable due to excessive deposits.

The above description of material accumulation on streets is presented in equation form below:²²

$$\begin{array}{ll} \text{Deposition:} & \frac{dL_d}{dt} = k_1 \end{array} \quad (\text{eq.7})$$

$$\begin{array}{ll} \text{Removal:} & \frac{dL_r}{dt} = k_2 L \end{array} \quad (\text{eq.8})$$

$$\begin{array}{ll} \text{Net accumulation:} & \frac{dL}{dt} = k_1 - k_2 L \end{array} \quad (\text{eq.9})$$

$$\begin{array}{ll} \text{Loading (integration} & L = \frac{k_1}{k_2} - \frac{k_1}{k_2} e^{-k_2 t} \\ \text{of eq.9):} & \end{array} \quad (\text{eq.10})$$

where L = street surface loading at
time t

k_1 = deposition rate

k_2 = fractional removal

When the rate of removal equals the rate of deposition, the loading remains constant at its maximum value:

$$\frac{dL}{dt} = 0$$

$$L_{\max} = \frac{k_1}{k_2} \quad (\text{eq. 11})$$

$$L = L_{\max} (1 - e^{-k_2 t}) \quad (\text{eq. 12})$$

As indicated by equation 12, the loading at any time is probably best expressed in terms of the street's maximum loading and the time since rain or cleaning. Although an attempt was made to derive empirical values for k_1 and k_2 and to incorporate the intermittent removal processes in the series of equations, the large number of secondary variables which affect the deposition and removal rates caused this effort to be dropped. Some of the secondary variables are: surrounding land use and surfaces, street surface type and condition, presence of curbing, traffic volume and mix, public works practices, season, etc.

From a time series of street loading measurements taken on Hamilton Avenue in Cincinnati, a curve of loading versus time was constructed, as shown in Figure B-2. The discrete measurement points are connected by straight lines. There appears to have been a fairly consistent maximum loading of about 1000 g/100 ft (116 lb/curb-mi) during the flushing period and of 1500 g/100 ft (175 lb/curb-mi) during the rest of the study. The accumulation rates for periods which were not interrupted by rain are presented in Table B-5. When averaged, the accumulation rates produce the characteristic curve such as described in equation 12:

Table B-5. ACCUMULATION RATE ON HAMILTON AVENUE, CINCINNATI

Date	Days since cleaning	Increase in loading, gm/100 ft.	Increase per day	Increase in traffic lanes	Increase per day in traffic lanes
10/07-10/08	0-1	-205	-205	-10.1	-10.1
10/10-10/12	0-2	170	85	-7.9	-4.0
10/14-10/19	0-5	355	71	-0.4	-0.1
10/25-10/26	1-2	-160	-160		
10/26-10/27	2-3	177	177		
11/04-11/05	0-1	237	237		
11/07-11/09	0-2	991	495		
11/11-11/23	0-12	1032	86		
12/09-12/10	0-1	890	890		
12/11-12/14	0-3	739	246		

Av. increase on first day = 307 gm/100 ft
 Av. increase on second day = 129
 Av. increase on third day = 240
 Av. increase on >3rd day = <10

APPENDIX C

PROJECT FIELD STUDIES

STREET CLEANING IN KANSAS CITY, MISSOURI

Study Design

The primary purpose of this study was to determine the effect of alternative street cleaning methods on particulate air quality in the area being cleaned. Two street cleaning methods were evaluated: broom sweeping and flushing. Streets in the study area were cleaned once weekly for a period of one month with each type of equipment. Also, the streets were not cleaned for a one-month period. Particulate concentrations were measured daily at eight sampling sites in the study area for the entire three months. Average concentrations associated with each cleaning period were compared after being adjusted to account for differences in regional particulate concentrations during the three periods.

The four by seven block study area was located in a commercial/warehousing district just south of Kansas City's central business district (CBD). Almost all the streets in the area have average daily traffic (ADT) volumes of 4,000 to 15,000 vehicles. A six-lane freeway separates this area from the CBD. Many parking lots within the area are unpaved or poorly paved. There are also several truck docks, salvage yards, body shops, and other businesses which might contribute to dirty streets.

Four of the eight samplers were located in one block of McGee Street, at heights of 5 and 20 ft on two poles on opposite sides of the street. Much of the auxiliary data for this study, such as traffic counts and street surface loadings, were monitored at this location. The other four samplers were placed on rooftops on the periphery of the study area, as shown in Figure C-1, for the dual purposes of determining the impact of the street cleaning at different points in the study area and of monitoring incoming air



Figure C-1. Kansas City street cleaning study area.

quality. Two of the peripheral samplers were directionally-activated units at the same location, one sampling when wind direction was from the north (CBD and freeway) and the other when winds were from the south (commercial/warehousing study area).

The day before and the day of each cleaning, street loading measurements were taken on McGee Street. This provided an estimate of the removal efficiency of each cleaning operation. Particle size distributions of material collected from the street were determined so that cleaning efficiency by particle size could also be estimated.

The data collected in this study were used in several other pertinent analyses, such as:

- changes in air quality and street loadings as a function of time since last cleaning,
- effect of rainfall on street loadings and air quality, and
- variations in daily concentrations across the study area.

Data from Study

Particulate concentrations at the four sites on McGee Street for the three-month sampling period are plotted in Figure C-2. The data indicate that concentrations were relatively uniform at the four sites on any one day in comparison with the day-to-day variations at all the sites. The four peripheral sites (not shown in Figure C-2) also had daily concentrations very close to those at the McGee Street sites, so there was generally little variation in daily concentrations across the study area. The plot of daily data also showed a consistent weekly pattern of concentrations with low concentrations on weekends, slightly higher concentrations on Mondays, and usually high concentrations on the other weekdays. The weekly pattern was attributed to differences

in daily traffic in the study area. Available traffic counts supported this hypothesis, as previously discussed in Appendix A (see Figure A-2).

The differences in average concentrations during the three cleaning periods were discussed in detail in Chapter 3 of the report. The effect of rainfall on ambient concentrations was also discussed at that time.

STREET CLEANING IN CINCINNATI

Study Design

The purpose and approach for this study were the same as for the Kansas City street cleaning study--a comparison of particulate concentrations in a five by seven block area during periods with different street cleaning methods. In Cincinnati, three cleaning methods (flushing, broom sweeping, and vacuum sweeping) were evaluated for one month each, plus there was no street cleaning for a noncontinuous one-month period.

The Cincinnati study area, shown in Figure C-3, was located in a primarily residential area with one commercial street, Hamilton Avenue. This street has an ADT of 17,700 but most other streets in the area have less than 1,000 vehicles per day. All streets are curbed and clean in appearance.

Seven samplers were placed in the study area and operated daily--four on two poles on opposite sides of Hamilton Avenue and three on rooftops at the locations shown in Figure C-3. Street loading measurements were taken on Hamilton Avenue.

Data from Study

Particulate concentrations at the four sites on Hamilton Avenue for the four-month sampling period are plotted in Figure C-4. Concentrations in the Cincinnati study area were much lower than in Kansas City, and the impact from traffic-related emissions appeared to be much less. Daily particulate levels were fairly uniform at the seven sampling sites, with the ground-level (5 ft) sampler on the east side of Hamilton Avenue averaging only about 15 ug/m^3 (geometric mean) higher than the site farthest from that street. The relatively low readings at the sites nearest Hamilton Avenue

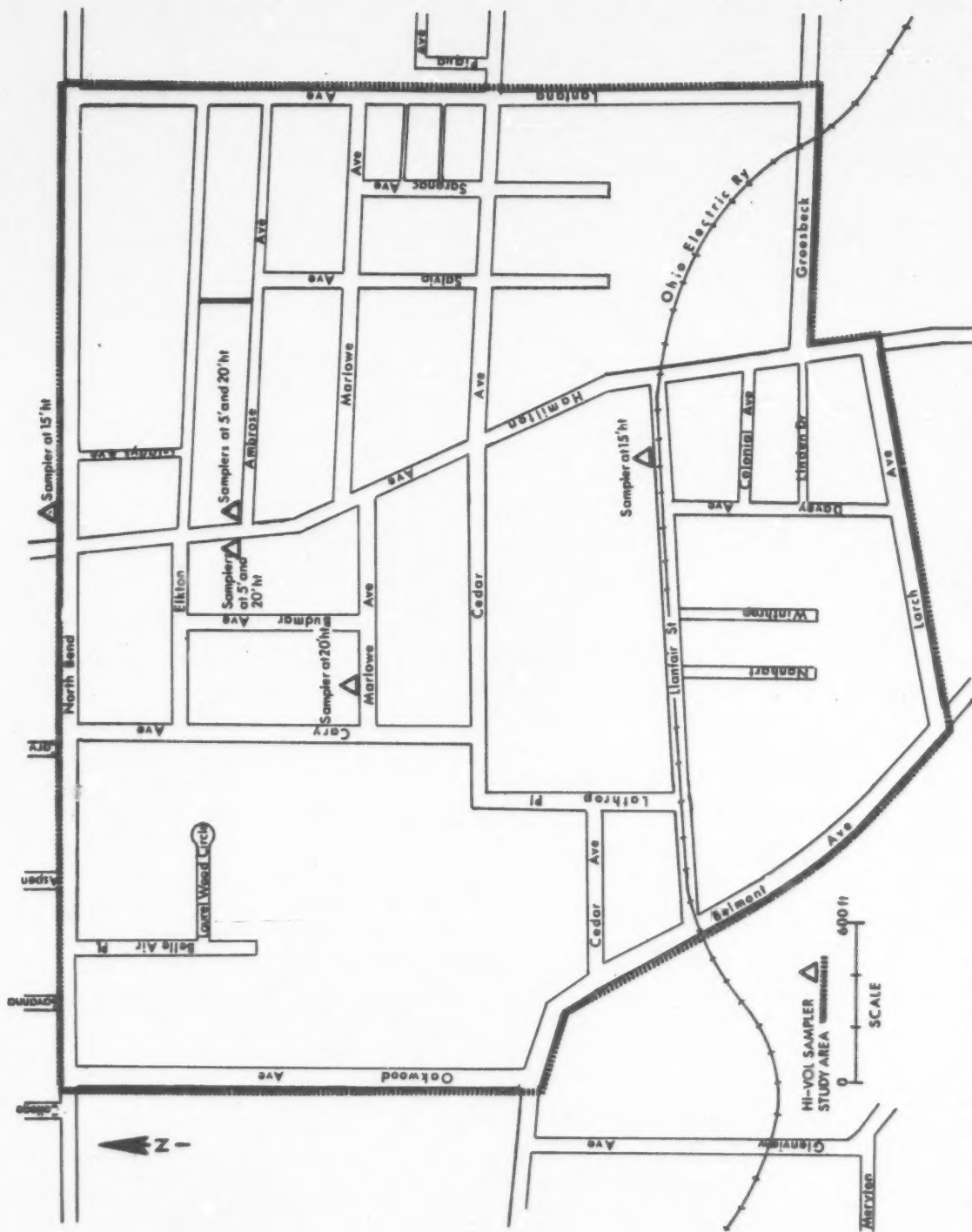


Figure C-3. Cincinnati street cleaning study area.

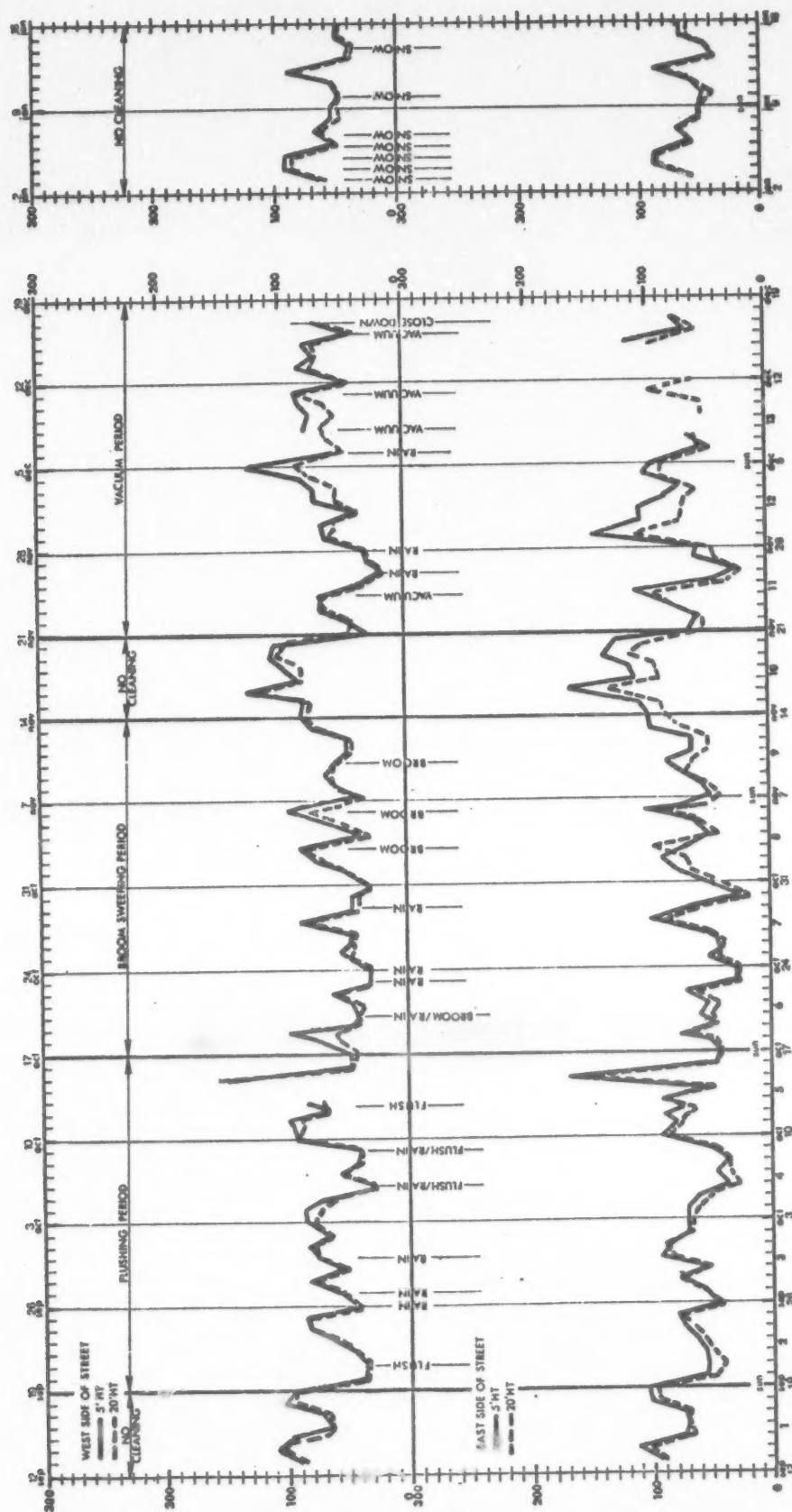


Figure C-4. Daily particulate concentrations for Hamilton Avenue site, Cincinnati.

and moderate concentration gradient with distance away from that major street were attributed to low reentrained dust emission rates from this clean street compared to the streets in the commercial/warehousing study area in Kansas City.

No distinct weekly pattern of concentrations was seen. Differences between weekday and weekend concentrations were not expected, since traffic data previously summarized in Table A-1 indicated that traffic volumes were approximately the same for weekdays and weekends.

The differences in average concentrations during the four cleaning periods were already discussed in Chapter 3 of the report.

Rainfall obviously reduced concentrations on days when it occurred. In the Cincinnati study area, the average reduction in concentrations on days with 0.1 inch or more of rain was 18 ug/m^3 ; in the Kansas City street cleaning study, rain reduced concentrations by 28 ug/m^3 . However, on the first day after a rain only a minimal residual effect was observed (e.g., from moist street surfaces) and on subsequent days no residual effect was noted. A similar impact from rainfall has been reported for other cities, as shown in Figure C-5.

If part of the reduction in concentrations on days with rain is from suppression of reentrained dust and from washing of street surfaces, then street flushing by trucks should have a similar effect on particulate concentrations after the flushing. In the Cincinnati study, the change in concentrations as a function of days after flushing was almost identical to that for rain-- 16 ug/m^3 less than average on days with flushing and 4 ug/m^3 less than average on the following day. These data are presented in Figure C-6. Days with flushing in Kansas City inexplicably showed higher than average concentrations, although concentrations on the first days following flushing were slightly lower than

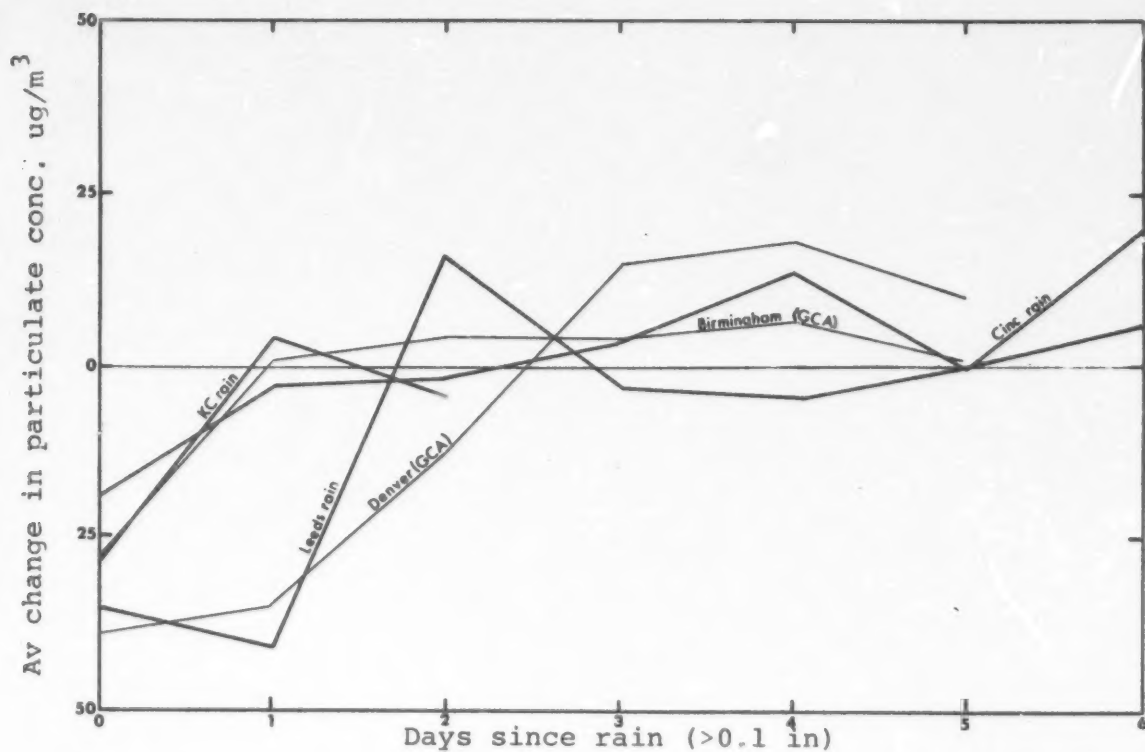


Figure C-5 Effectiveness of rainfall in reducing particulate concentrations.

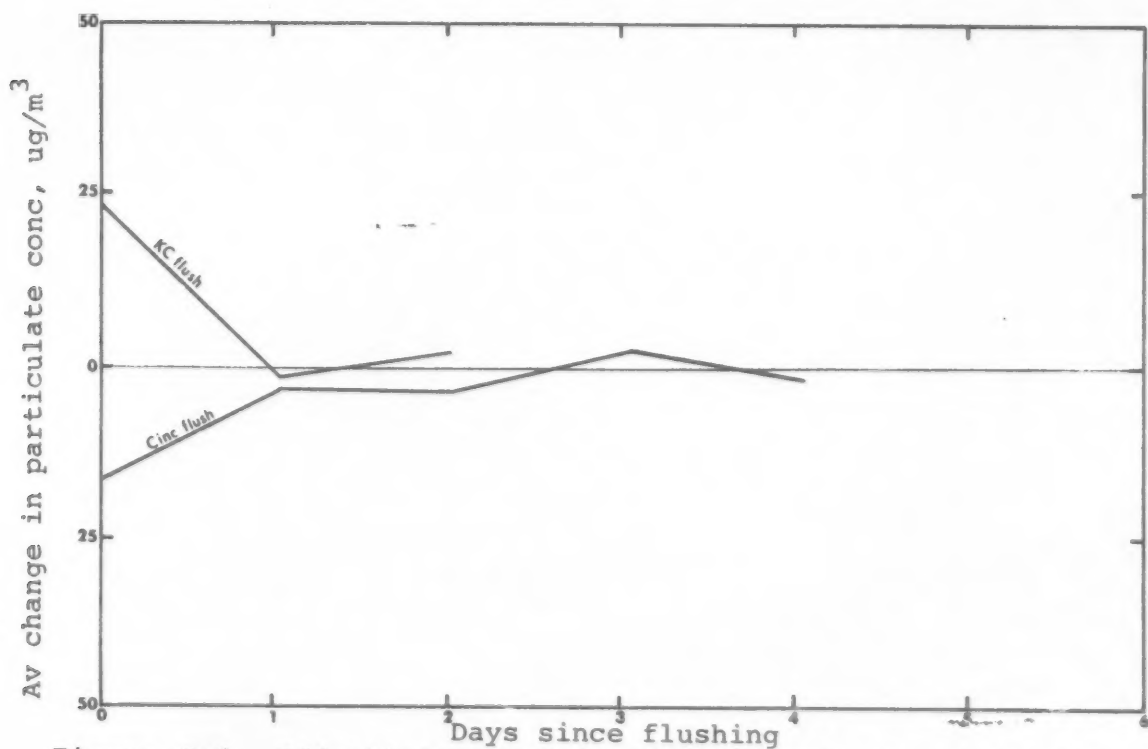


Figure C-6 Effectiveness of flushing in reducing particulate concentrations.

average. Based on the curves of concentration versus days since rainfall and the Cincinnati flushing data, it appears that daily or every other day flushing might provide a substantial reduction in ambient concentrations.

The characteristic change in particulate concentrations following broom sweeper cleaning in Cincinnati was a moderate increase on the day of cleaning, a definite reduction on the day after cleaning, and then a gradual increase of concentrations for the next few days, as shown in Figure C-7. The data from the Kansas City street cleaning study demonstrated the same changes in concentrations after broom sweeping except for a much sharper increase in concentrations on the second and third days after sweeping. The higher than average concentrations on days with broom sweeping are probably caused by the cleaning operations breaking material loose from the street surface, redistributing it, and temporarily making more material available for reentrainment.

On days following vacuum sweeping in the Cincinnati study area, the change in particulate concentrations was almost identical to that for broom sweeping--a moderate increase on the day of cleaning, a definite decrease on the next day, and then a gradual increase in concentrations on successive days. The curve of concentration versus time was also presented in Figure C-7. Although vacuum sweepers do not have the mechanical action against the street surface that would tend to break down aggregated particles and redistribute material on the surface, they apparently cause some temporary increase in the amount of material available for reentrainment on the day of cleaning. The steady increase in concentrations starting with the second day after either broom or vacuum sweeping indicates that cleaning at two- or three-day intervals might be optimum from an air quality standpoint.

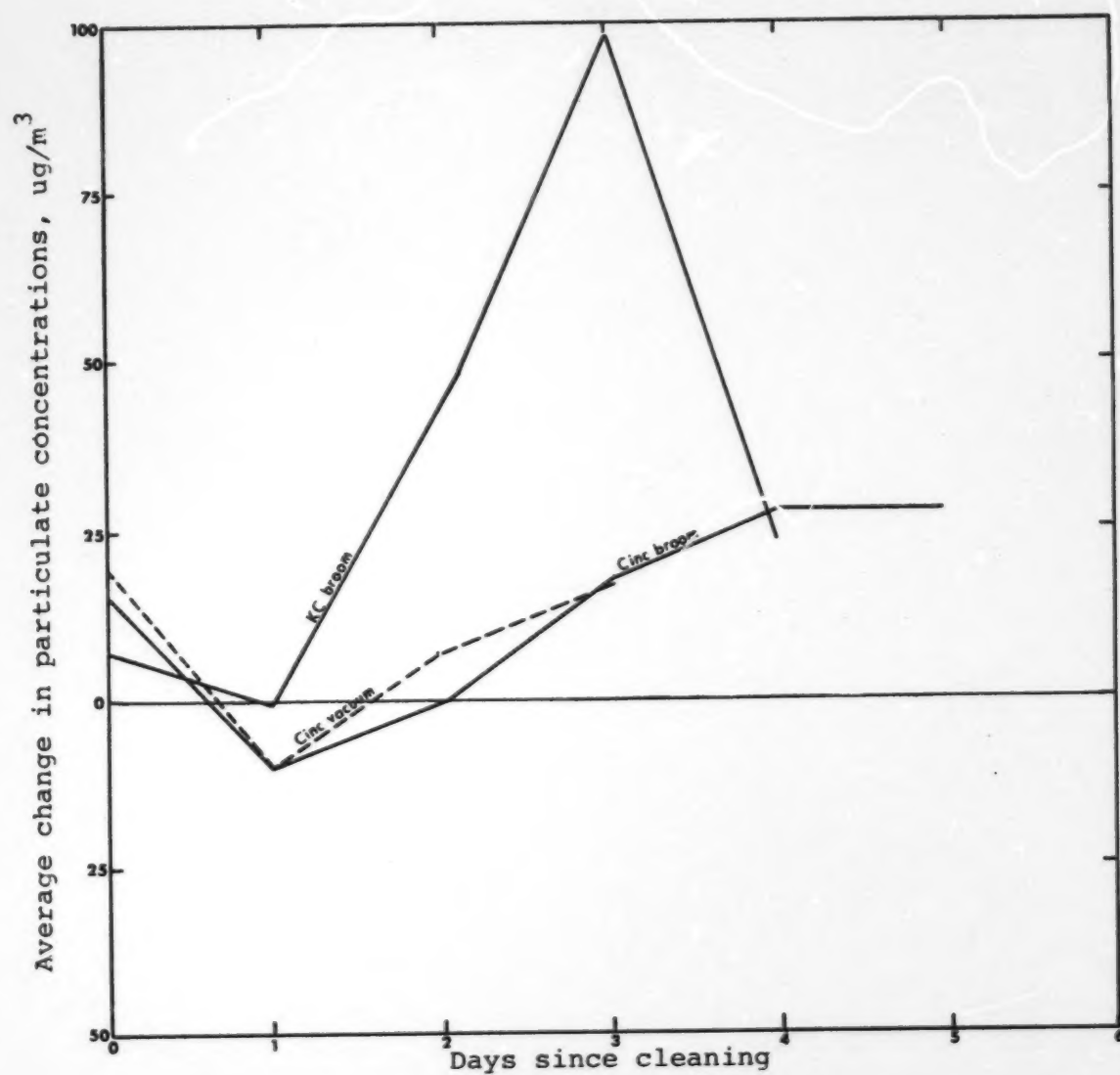


Figure C-7 Effectiveness of street cleaning in reducing particulate concentrations.

STREET CLEANING IN RESIDENTIAL AREAS

The study design and data for comparison of air quality in two suburban residential communities with different street cleaning programs were presented in reasonable detail in Chapter 3.

CONSTRUCTION SITE

Study Design

This study was designed to evaluate the effect on air quality of potential control measures for reducing the amount of material deposited on streets from a major mud carryout source. The control methods evaluated were frequent cleaning of the access area with municipal street cleaners, and cleaning of the access area manually with broom and shovel. A one-time tracer study was also conducted at this site to determine how far material is distributed from its initial carryout point by traffic on the nearby streets.

Four high volume samplers were placed at three locations near a building construction site in Kansas City, as shown in Figure C-8. The two westerly samplers were located on the roofs of one-story buildings about one block west of the single, well-defined access point to the construction site. The third and fourth samplers were placed on the roof of a building near the eastern edge of the construction site on 43rd Street. These two samplers were directionally activated when the wind was from the north (270° to 090°) or south (090° to 270°). Locating samplers in both directions from the access point assured that the impact of mud carryout would be monitored even if the mud tracking was concentrated in one direction. The sampling sites to the west were far enough away from the construction area that fugitive dust from the site itself did not cause a bias. However, lack of suitable sampling sites at a corresponding distance east of the site prevented a similar sampler configuration in that direction.

A log of construction activities and truck traffic at the site was maintained during the study period. Truck traffic was greatest during September and early October (the

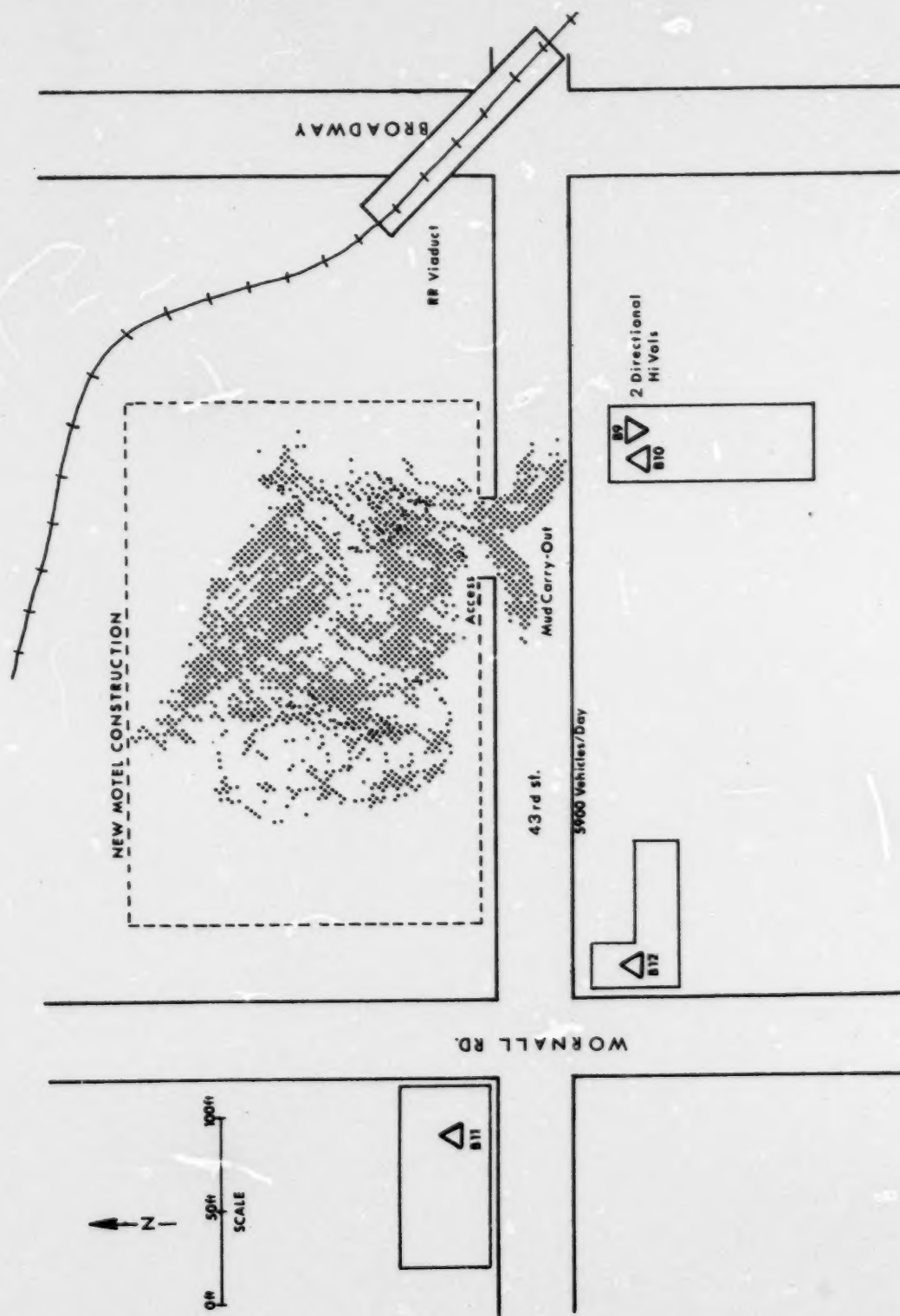


Figure C-8. Location of high volume samplers at construction site.

no control period). However, the trackout during late October, November, and December was comparable because construction workers began using the construction area for parking.

Data from Study

Particulate air quality in the vicinity of the construction site was greatly affected by excess reentrained dust caused by material tracked from the site. Concentrations were 40 to 60 ug/m³ (geometric mean) higher at the four sites in the study area than at the closest sampler locations in the regional network.

Comparison of particulate levels during the different control periods (presented in Table 3-5 of the report) reveals that concentrations were lowest when the access area had intensive manual cleaning, next lowest when manual cleaning was done intermittently, third lowest during the no control period, and highest when municipal street cleaning equipment was used along the access street. The results of the municipal street cleaning period require some further explanation. Three blocks of the access street, 43rd Street, were flushed on Monday, October 25 and Friday, October 29. The same area was swept with a broom sweeper on Thursday, October 28. The air quality data by day indicate that the street flushing may have increased mud carryout from the site and the transport of street surface material away from the immediate area of the construction site access road. Because material was removed by the broom sweeper only once during the week, the result appears to have been more material than usual available for reentrainment.

This construction site study was not a controlled experiment--the material being tracked from the site was not constant over time and no method for measuring or quantifying the amount of material carried out could be devised.

Also, visual observations of street cleanliness reported in the log did not always agree with particulate concentrations at the sampling sites for the same time periods. Any quantitative conclusions from this study must be qualified by these limitations.

The area of impact around a major mud carryout site was estimated by means of a tracer study. A mixture of sand and zinc oxide powder containing 6 lb of zinc oxide was spread evenly across 43rd Street at the entrance to the construction site. Samples of street dust at 50 locations at distances from 200 ft to 3000 ft from the entrance were taken one day before, one day after, and eight days after the tracer was released. Although the data contained scatter due to nonuniform dispersal of the tracer, there were definite elevated levels of zinc for about 1500 ft along 43rd Street on the day after the tracer was released. None of the material collected from surrounding streets showed significant changes in zinc concentrations on the first day. However, after eight days, elevated zinc levels were detected for 400 ft in one direction (west) and 2000 ft in the other direction on 43rd Street and for 0.5 mi north of 43rd Street on Broadway and the next major north-south arterial to the east, Main Street. There were also some high zinc levels on Broadway and Main Street south of 43rd Street. The tracer study showed that the distance of tracking is very irregular and seems to depend on the relative traffic volumes on different streets carrying traffic away from the mud carryout source. The major impact area for reentrained dust is probably confined to a distance of 1000 ft in either direction along the primary access street.

SHORT-TERM SAMPLING STUDY

Study Design

The primary purpose of this study was to obtain concurrent data on particulate air quality, street surface loadings, and traffic volumes at several different test locations so that general interrelations among these variables could be determined. It was important to establish a direct relationship between street loadings and particulate concentrations because most of the proposed control measures for reentrained dust are based on reducing average street loadings by cleaning techniques or by preventing material from reaching the streets.

Secondary objectives of this study were to investigate the effect on air quality of:

- ° distance from the street curb,
- ° traffic speed, and
- ° wind speed.

At each test location, the portable high volume samplers were placed at distances of 10, 20, and 30 m from the street curb in the direction parallel to the wind direction at the beginning of the sampling period, as shown in Figure C-9. Another portable sampler was placed upwind of the street. The samplers and wind instrument were run for a continuous sampling period of one to two hours.

Prior to or after the sampling period (so that traffic flow was not interrupted), the street surface loading on a cross-section downwind from the test site was measured by collecting vacuuming samples. With the push type vacuum device, it was necessary to close single lanes of the street while the samples were being taken. The weight and particle size distribution of material collected from the street was determined in the laboratory.

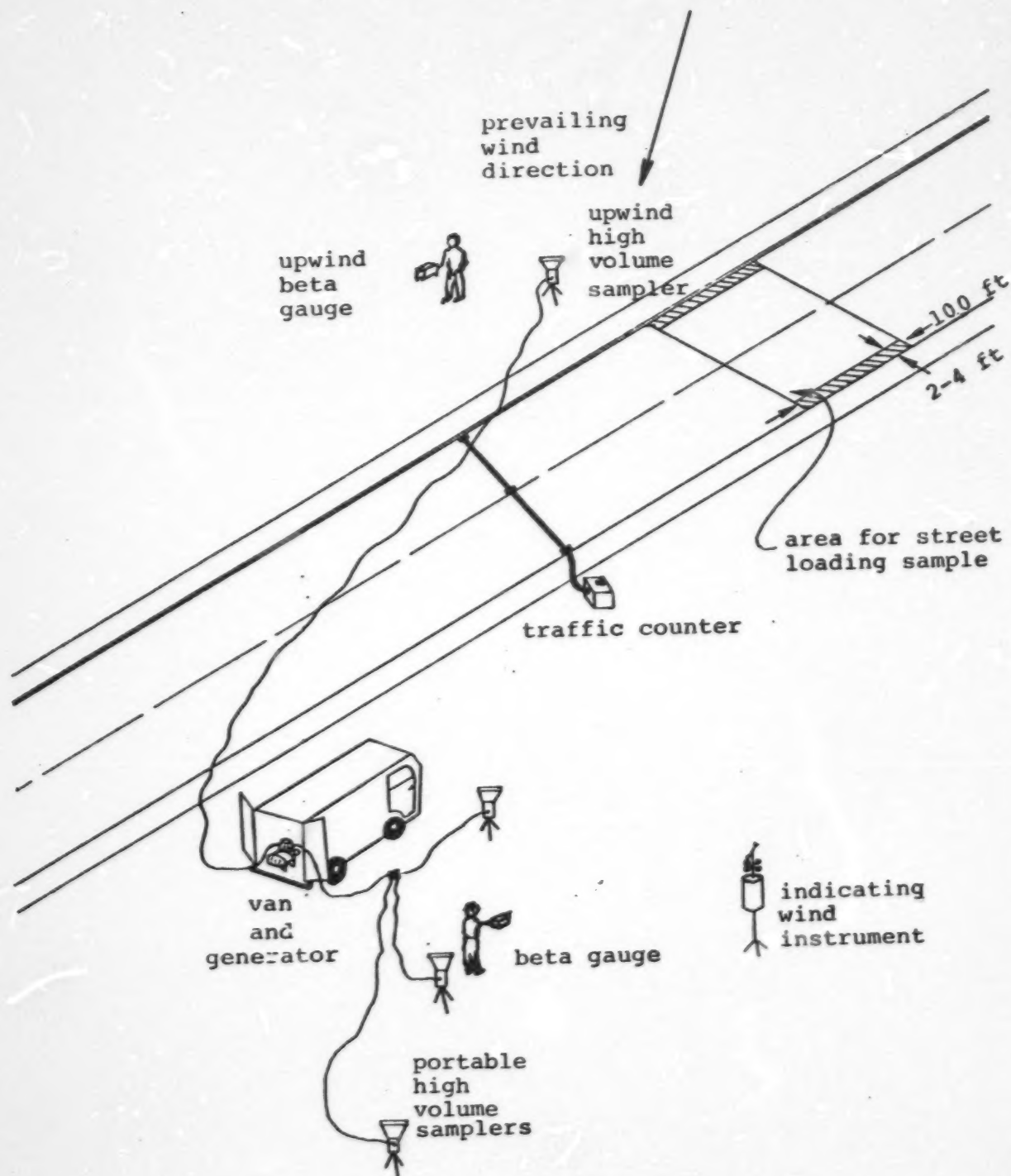


Figure C-9. Sketch of typical sampling setup.

Traffic counts were tabulated by a mechanical counter and recorded for the total sampling period. The average traffic speed during the test period was determined by driving a vehicle along the street with the traffic flow. Wind direction and velocity was recorded at two minute intervals during the sampling period.

The high volume samplers require electrical power. Since the sites were in fairly open areas, a power source was not usually readily available; therefore, a 5 kw mobile generator was used as standard fixed equipment in the van.

Data from Study

A total of 60 sampling periods were conducted at five test sites. For 35 of these sampling periods, wind direction remained fairly consistent with the original upwind-downwind configuration more than 90 percent of the time. Data from these periods, shown in Table C-1, were used in subsequent analyses. Data for the remaining 25 sampling periods are presented in Table C-2. These values were not used in any data analyses because of the difficulty in determining net downwind concentrations.

The analyses of short-term downwind samples were already described in Appendix A. The results of multiple linear regression with traffic volume, street surface loading, traffic speed, and wind speed as the independent variables were presented starting on page A-6. Calculation of estimated emission rates from the downwind ambient concentrations, using a line source Gaussian dispersion equation, was presented starting on page A-15. The important findings are summarized below:

- ° Concentrations measured 10 m downwind of the streets were an average of 67.9 ug/m^3 higher than ambient concentrations in the same area.

Table C-1. SUSPENDED PARTICULATE CONCENTRATIONS FOR
SHORT-TERM SAMPLING STUDIES WITH
CONSISTENT WIND DIRECTIONS

Study no.	Suspended particulate concentration, $\mu\text{g}/\text{m}^3$			
	10 m upwind	10 m downwind	20 m downwind	30 m downwind
3	90.0	167.8	131.4	124.2
4	35.8	82.5	76.4	95.5
7	54.6	139.9	113.9	89.6
10	53.4	143.9	107.8	93.0
12	143.7	177.8	151.5	145.8
13	351.7	391.9	357.4	334.0
16	29.9	65.8	50.8	50.1
18	76.2	93.0	81.7	79.1
20	90.0	99.6	91.6	106.6
22	30.7	93.6	68.5	62.7
23	8.3	51.2	45.3	49.5
25	71.4	120.1	119.8	86.7
26	26.3	98.6	67.0	50.8
27	69.3	142.5	129.2	106.1
28	56.1	188.2	175.8	147.3
29	111.4	147.9	135.1	133.8
30	64.1	144.4	135.4	132.6
31	120.2	182.3	173.6	161.8
34	12.2	42.3	14.9	4.9
37	53.0	99.1	80.6	63.9
38	43.4	128.9	105.9	70.3
39	10.2	55.0	39.1	17.1
40	16.8	182.9	149.2	91.2
41	53.5	108.2	74.4	92.3
42	33.3	64.0	49.2	42.9
43	41.6	114.9	85.6	71.8
45	66.8	128.0	106.6	110.2
47	191.8	256.4	221.3	201.3
49	67.3	138.3	96.9	89.8
50	26.1	102.5	84.1	59.5
51	76.0	166.4	133.7	89.3
52	105.0	195.3	163.4	141.8
54	179.3	327.9	275.0	254.7
56	78.3	177.4	129.8	116.4
57	85.1	183.6	166.1	121.6
av	75.0	142.9	119.7	104.5
std dev	64.9	72.7	67.1	62.7

Table C-2. SUSPENDED PARTICULATE CONCENTRATIONS FOR
SHORT-TERM SAMPLING STUDIES WITH
VARIABLE WIND DIRECTIONS

Study no.	Suspended particulate concentration, $\mu\text{g}/\text{m}^3$			
	10 m upwind	10 m downwind	20 m downwind	30 m downwind
1	73.0	62.7	61.9	56.5
2	77.8	81.6	71.1	68.5
5	130.0	105.1	89.9	90.0
6	98.6	120.5	95.4	85.6
8	31.4	37.0	30.2	29.3
9	44.8	67.1	57.2	52.6
11	52.6	47.6	49.8	48.2
14	78.6	205.0	189.1	185.0
15	114.8	129.8	103.7	105.7
17	103.0	76.7	58.4	47.5
19	54.8	104.9	86.3	93.8
21	66.6	87.7	58.7	65.5
24	32.3	42.5	31.0	48.1
32	24.1	31.0	35.0	36.7
33	78.5	72.2	52.0	54.1
35	60.4	77.0	58.6	38.9
36	95.8	68.1	56.7	43.3
44	69.6	73.2	84.8	82.4
46	74.4	136.1	94.8	94.7
48	136.7	269.4	220.2	184.6
53	105.3	199.5	147.4	115.5
55	388.6	550.1	471.9	437.0
58	324.8	330.7	295.6	264.4
59	256.3	259.6	196.5	193.9
60	254.0	255.5	188.6	203.3
av	113.1	139.6	115.0	109.0
std dev	93.3	119.0	100.7	92.6

- ° Concentrations were more closely related to traffic volume along the street than to any of the other variables evaluated.
- ° No relationship was found between street surface loadings and particulate concentrations near the street.
- ° Wind speed had a direct rather than inverse relationship with the net downwind concentrations. Although the correlation was low (0.28 to 0.40), it indicated that the dust generating and transport effects of increased wind speed more than offset its diluting effects.
- ° There was a slight inverse relationship between traffic speeds and concentrations.
- ° The average emission rate calculated from the downwind concentrations was 3.7 g/veh-mi, with a standard deviation of 3.3 g/veh-mi.
- ° Variations in emission rates from four different streets were not very great.
- ° The deposition of material reentrained from streets appears to follow traditional particulate deposition curves in which the rate of fallout with distance is a function of atmospheric stability, wind speed, and the settling velocity of the particles. The settling velocity which best fit the data was 5 cm/sec.

METHOD FOR MEASURING STREET SURFACE LOADINGS

OBJECTIVES AND SCOPE

A procedure has been developed to enable the quantitative measurement of material loadings (in lb/sq ft and lb/curb-mi) and the particle size distribution of deposited material on paved streets.

The methodology is similar to that of the measurement procedure developed by EPA's Office of Research and Development and several key design elements have been retained. Most of the operational aspects are dissimilar, however, since the EPA procedure was developed for analyses associated with water quality applications, in contrast to the current method, which will be utilized in conjunction with field studies on the air quality impacts of reentrained dust from streets.

In particular, the variables to be measured are:

- ° the total street surface material loading on a 100 ft length section of street over a cross-section width measured from curb to curb, to include all naturally* occurring material found thereon;
- ° the percent of material in the active traffic lanes (defined as the total area extending across the crown of the street to within approximately 24 in. of each

* Street dust, dirt, leaves, bottle caps, etc. Obviously, a cement block which has fallen off a truck is not naturally occurring.

curb) versus the percent accumulated within 24 in. of the two curbs, to be determined by the acquisition of two separate samples:

- the particle size distribution of the curb and traffic lane samples;

PARAMETERS TO BE MEASURED AND EQUIPMENT

- | | | |
|----|-------------------------------------|---|
| 1. | Street surface particulate loadings | broom
ROOF-push vacuum
vacuum with disposable sample bags
portable generator
chalk/tape measure
traffic safety cones |
| 2. | Particle size distribution | rotary sieves (to 37/um)
analytical balance |

DESIGN

Samples of materials deposited on streets will be collected using a combination of sweeping (broom) and vacuuming techniques to determine the total particulate street surface loading and the size distribution of said material on any particular 100 ft test section. The procedure assumes that the street loading is uniform along any given street which is otherwise free from biasing due to localized mud trackout, etc. Further, it is assumed that a 100 ft test section will produce an accurate and reproducible sample.

The material removed will be collected in a stepwise fashion and segregated into two samples: the fraction deposited within 24 in. of both curbs and the fraction deposited over the remaining surface of the street. The procedure entails a preliminary brooming of the 2-24 in. wide 100 ft curb areas, followed by a thorough vacuuming with a push-vac. The collected material constitutes one sample. The remaining road surface area over the active traffic lanes will then be vacuumed (not initially broomed)

with the push-vac to gather the second sample for the site. It is emphasized that final flushing is not employed to collect the residual matter remaining after vacuuming because the primary purpose of flushing is to collect water soluble components present in low mass quantities. The present procedure was designed for the collection of particulate matter only, so it was determined that flushing was unnecessary.

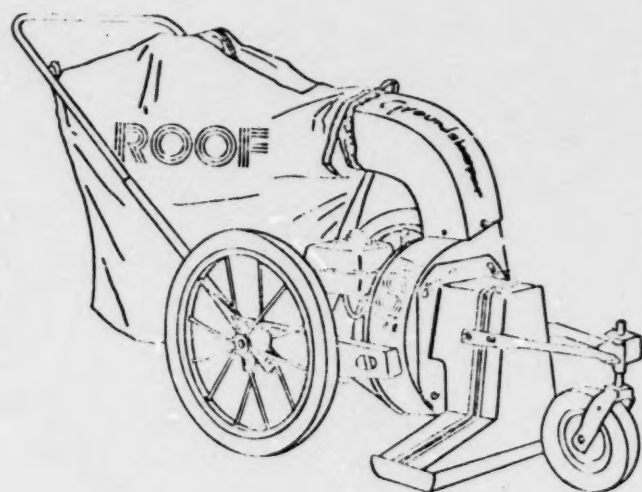
The designs of the fixed street cleaning studies in Kansas City, Missouri and Cincinnati require that at least two street loading samples be taken per week, one before the streets are swept and one after. The locations for taking the samples will be chosen such that they are not immediately fronting any of the hi vol samplers in the study area. This will minimize the introduction of bias into the measured air quality at these locations due to the possibility of the street loading sampling (actually a sweeping and cleaning operation) producing artificially clean streets and low particulate concentrations adjacent to the sampler. In addition, there will be two different areas chosen for street surface sampling, one for the "before sweeping" sample, and one for the "after sweeping" sample. The two 100 ft sections should preferably be on the same street, since a basic assumption with this procedure is that loadings are uniform over a given street section subject to the same traffic, environmental influences, and sweeping technique and patterns. Using two areas in this manner will ensure that a representative sample is taken both before and after the streets are swept.

For the mobile studies conducted in Kansas City, six street loading sampling areas will be chosen on streets with medium traffic densities and bordered by expanses of open areas where air sampling equipment may be extended and set up. The medium traffic flow will ensure ease and rapidity of sample collection, facilitate personnel safety, and

result in minimum disruption of traffic flow. Of course, the streets will be chosen so as to minimize biases to the sample collection process due to the proximity of storm drains, crosswalks, steep grades, heavy parking activity, active mud carry out sites, or other activities which could result in acquisition of a nonrepresentative sample.

The most dominant aspect of this design for the street loading sampling procedure is the utilization of the multi-purpose ROOF-Groundskeeper--a gasoline powered, push type, vacuum machine. This machine incorporates a powerful 5 hp high rpm (3600) engine to drive a high volume centrifugal impeller which provides the necessary suction to pick up virtually 100 percent of the material encountered on a street surface, including rocks and litter. Most importantly, it greatly reduces the time required for sample collection over large areas and provides for operator safety by limiting exposure time in the active traffic lanes of the street. The machine is shown in Figure 1.

Material is collected in a large fabric dust bag behind the machine, as shown. Fine particulates are trapped in the interstitial fibers of the fabric. After collection, the sampled material must be transferred to a suitable sample storage container until weighing and analysis takes place. This is accomplished by vacuuming the material from the inside of the bag with a standard household type vacuum cleaner. The material is collected in a disposable type filter bag which can be removed from the vacuum, sealed, and retained quite conveniently for analysis. It was estimated that this two-step procedure is approximately 85 percent efficient at collecting material from the street surface. This efficiency was determined by collecting material directly with the household vacuum over a 50 ft length of street and comparing the weight with that obtained using the standard collection procedure on an adjacent 50 ft section.



D-1. Machine used for collection of street loading samples.

The samples will be shipped weekly to PEDCo's laboratory in Cincinnati where they will be weighed to determine the street surface loading and analyzed to determine the particle size distribution. Initially, several sample bags will be equilibrated and weighed so that an average tare bag weight may be determined. In this fashion, the net sample weight may be calculated. It is estimated that the weight of the bags will be insignificant (1 oz) as compared to the weight of the sample (1-2 lb); therefore, variations in bag weight should be relatively unimportant.

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